# Popular Astronomy

Vol. LIX, No. 8 OCTOBER, 1951 Whole No. 588

## Double Star Interferometry*

By W. S. FINSEN

### Introduction: Resolving Power of a Telescope

Every serious user of a telescope is familiar with the concept of resolving power. If the telescope is directed to a bright star (which may to all intents and purposes be regarded as a point source) its image as seen with the telescope is not a luminous point but a disc, known as the diffraction, spurious or Airy disc. Under ideal conditions this disc is surrounded by several concentric rings of diminishing brightness. If the star we are looking at happens to be a double star with components of equal brightness (for simplicity) then the question whether we shall be able to resolve it depends on the angular separation of the components relative to the angular size of this disc. If the separation of the double star is small compared with the diffraction disc the pair will not be resolved; instead of seeing a separate and distinct disc for each component we shall see a single disc which under good conditions may be slightly elongated. Any attempt to improve matters by increasing the power of the eyepiece will be doomed to failure, resulting merely in an apparently larger and fainter disc without any gain in resolving power. Such pointless increase in magnification is often referred to as "empty" magnification.

This spurious disc can be explained on the basis of the wave theory of light. The classical work on the subject is that of Sir George Airy, published in 1834. He found that the angular radius of the first dark ring surrounding the central disc was simply $1.22\,\lambda/D$, where $\lambda$ is the wavelength of light and D is the diameter of the circular object glass. It may seem rather surprising that there is no mention of the *focal length* of the object glass. But the reason for this will be clear if we remember that $1.22\,\lambda/D$ is the *angular* radius of the first dark ring as subtended at the object glass. Its *linear* radius, on the other hand, is given by $1.22\,\lambda\,f/D$, which involves both focal length and diameter. In fact, f/D is merely the "focal ratio" F well known to photographers.

So we see that the *linear radius* of the first dark ring is directly proportional to the focal ratio, while the *angular* radius is inversely proportional to the diameter of the object glass. The first two telescopes depicted in Figure 1 have the same focal ratio and thus have diffraction discs of the same *linear* diameter. The third has a smaller focal ratio

*Presidential address delivered before the Astronomical Society of South Africa on July 26, 1950.

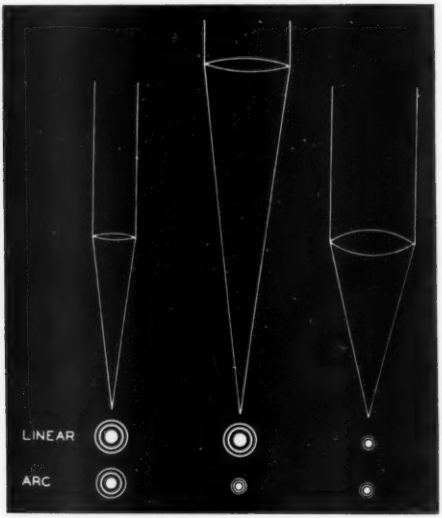



FIGURE 1

and thus yields a correspondingly smaller diffraction disc. However, when we consider the *angular* diameters of the discs, we see that the second and third telescopes, having object glasses of the same diameter, yield diffraction discs of the same *angular* diameter—the greater linear size of the second being compensated for by the telescope's longer focal length.

It is not possible to define resolving power precisely in terms of the size of the diffraction disc. Our diagrams are somewhat misleading, for in actuality the discs are without sharp borders. The intensity of illumination of the discs falls off gradually towards the edge, reaching zero at the first dark ring. It is convenient and for most purposes sufficiently accurate to adopt Lord Rayleigh's definition of resolving power and to regard two star images as resolved when the centre of one disc falls on the first dark ring of the other. In other words, the theoretical resolving power may be defined as $1.22\,\lambda/D$, or in seconds of arc, $5''.42/D$ where D is the diameter of the object glass in inches. In practice it is possible to do somewhat better than this, as shown by Dawes' well-known empirical limit for the resolution of an equal pair, which is $4''.56/D$. For a 26½-inch telescope these limits are $0''.20$ and $0''.17$ respectively.

### SLIT INTERFEROMETER

The stellar interferometer is a device for obtaining improved resolution with a given telescope. At A in Figure 2 we have an orthodox telescope with the diffraction disc formed by it represented on a great-

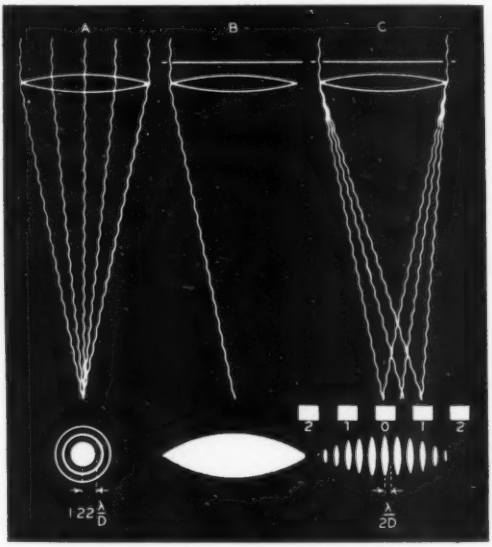



FIGURE 2

ly enlarged scale. For the present we will assume that the light source is a single oscillator emitting a continuous train of waves. At B a mask is placed in front of the object glass. This mask stops down the object glass to a narrow slit near one edge. The result is a diffraction disc of greatly increased size and no longer circular, leading to a great loss of resolution. But let us see what will happen if we cut a second slit in the mask at the other extremity of the diameter of the glass, as at C. On the axis we see a pair of rays, one from each slit, intersecting at 0. As the optical paths are identical, the waves arrive in phase and reinforce each other, resulting in a bright patch or fringe at 0. As we move away from the axis the path lengths become increasingly unequal. At 1 they differ, however, by exactly one wavelength. The waves are therefore again in phase, and the result is a second bright fringe. And so on for path differences of two, three and more wavelengths. But between these points, as for instance between 0 and 1, the waves arrive out of phase, and so neutralise each other and give rise to a dark fringe. The result is that the large diffraction disc is broken up into a series of alternately bright and dark fringes. Now it is easy to show that the angular spacing of the bright fringes is given by $\lambda/D$, where D is now the spacing of the slits. If we now imagine that the star we are looking at is a double with a separation of $\lambda/2D$ and with a position angle equal to that of the line joining the slits, then the bright fringes of the companion will fall on the dark fringes of the primary. The duplicity will

therefore be revealed by the more or less complete disappearance of the dark fringes.

Comparing the resolving power $1.22\,\lambda/D$ of the orthodox telescope with the value $\lambda/2D$ for a pair of slits spaced as widely as the object glass will allow, we see that the resolving power has been increased by a factor of 2.44.

Before going any further it is desirable that we understand clearly the dependence of the *linear* spacing of the fringes on the angle of convergence of the rays from the two slits. This is shown in Figure 3

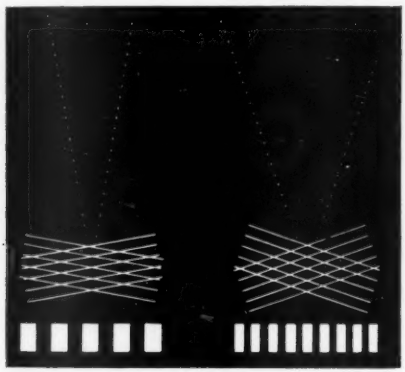


FIGURE 3

where successive wave fronts along each ray are represented by normals to the ray. Clearly, the more obtuse the angle of intersection of the wave fronts the closer the fringes will be. By analogy with the usage for an unobscured object glass, it is convenient to speak of the focal ratio $F = f/D$ of an interferometer, where f is the focal length and D the slit spacing. The linear spacing of the fringes is then simply $\lambda F$. For a normal refracting telescope F is about 16. With maximum separation of the slits the linear fringe spacing is then 0.00034 inches. To see the fringes clearly we would need an eyepiece of not more than one inch focal length.

## COHERENCE

Hitherto we have assumed for simplicity a point source consisting of a single oscillator emitting a continuous train of waves—or, in the case of a double star, two such point sources. But the argument is not affected if instead of a continuous train of waves we have, as in practice, short bursts of radiation in rapid succession. The fringe patterns resulting from each short train of waves will be coincident. This will still be true if the point source consists of a number of independent oscillators, provided each contributes a pair of rays passing through the slits. At any point on the diffraction disc the innumerable pairs of rays in-

tersecting there will then preserve a constant phase difference. Two beams of light intersecting in this way are described as "coherent." This is depicted on the left of Figure 4, the source of light being a

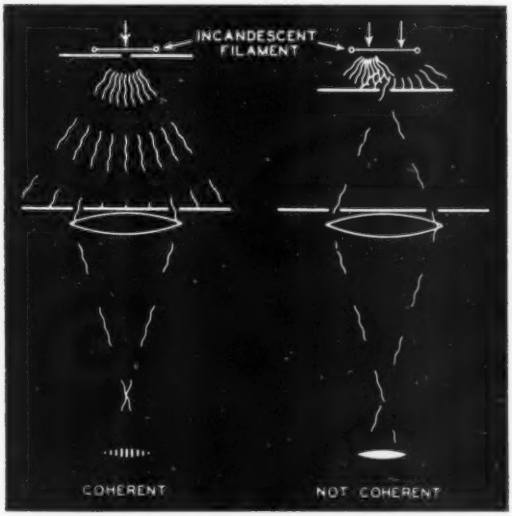



FIGURE 4

point on an incandescent filament isolated by a slit placed close to it. On the right, however, the isolating slit is placed a considerable distance in front of the filament, with the result that the rays entering the interferometer slits come from two different light sources. The phase difference at the focus will then vary in a completely random way, so that no interference pattern is built up. Such rays are not coherent.

In other words, two rays will give rise to interference fringes only if they are derived from a common source and if each pair of wave trains "collides" at the point of intersection.

### RESOLVING POWER DETERMINED BY ENTRANCE SLITS

If, then, we place a screen in front of the object glass of our telescope, with two slits as widely spaced as the object glass will allow (for maximum resolution), the image of a star will be transformed from the normal circular disc to a considerably larger pattern of interference fringes having the appearance of a measuring scale. In the case of a double star we shall have two such patterns or scales, and it will be possible to resolve such a pair if their separation is such that the bright fringes of one scale fall on the dark fringes of the other. We have also seen that the fringe spacing is governed by the angle of convergence of the two rays. It seems tempting, therefore, to increase the angle

of convergence still further (by means of prisms or mirrors) and so obtain closer fringes. Unfortunately, however, resolving power is not necessarily governed by fringe spacing, though this happens to be the case with the simple interferometer we have been discussing hitherto. If we increase the convergence angle without correspondingly increasing the slit spacing we can no longer regard the fringe patterns as simple measuring scales rigidly attached to the line of sight to the stars.

Figure 5 shows, on the left, our simple interferometer, pointed at a

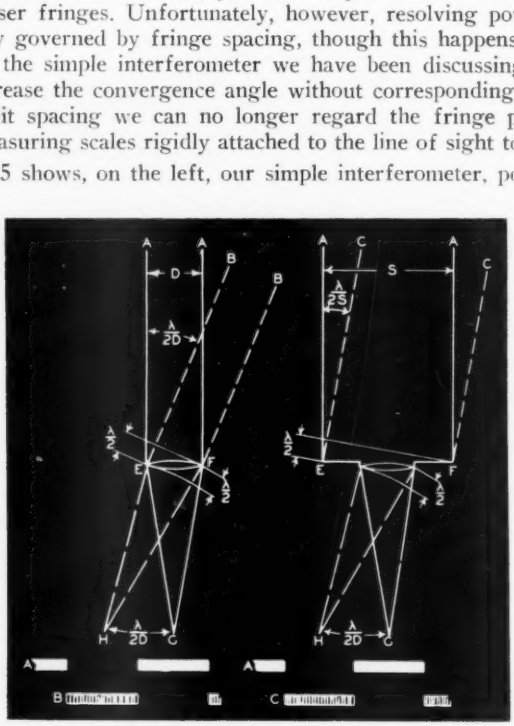



FIGURE 5

double star. Rays from component A (assumed to lie on the optical axis) pass through slits at E and F and intersect with zero path difference at G, which is therefore the position of the zero order bright fringe. A second pair of rays from E and F intersects at H with a path difference FH — EH of half a wavelength. H is therefore the position of the first dark fringe to the left. The angle between the dark fringe and the zero order fringe is then $\lambda/2D$ where $D = EF$. Assume now that the companion B lies in a direction EB such that its zero order bright fringe falls on the dark fringe H of the primary. Since H is the position of the zero order fringe of the companion B, the total path lengths BEH and BFH must be equal. But we know that $FH - EH = \lambda/2$. Therefore $BE - BF = \lambda/2$. The angle AEB subtended by the components is therefore $\lambda/2$ divided by D, i.e., $\lambda/2D$, as we originally assumed without proof.

Imagine now that we increase the separation of the slits from D to S

by means of two pairs of mirrors arranged like periscopes in front of the original slits (Figure 5, right). Assuming for simplicity that the paths EG and FG are again equal, the zero order fringe of the component A will again be situated at G, and, since the convergence angle of the two rays at G is unchanged, the first dark fringe will again be at H, making an angle $\lambda/2D$ with the zero order fringe. Now suppose that a companion C lies in a direction EC such that its zero order fringe falls at H. The total paths CEH, CFH must then be equal. But $FH - EH = \lambda/2$, and it follows that $CE - CF = \lambda/2$. Hence the angle AEC subtended by the components is $\lambda/2$ divided by S, i.e., $\lambda/2S$. So in this case the angular spacing $\lambda/2D$ of the zero order fringe and the first dark fringe corresponds to a resolving power $\lambda/2S$ instead of $\lambda/2D$. We have in fact increased the resolving power in the ratio S/D while retaining the fringe visibility corresponding to $\lambda/2D$, a very powerful advantage. It is evident that fringe spacing and resolving power are not necessarily synonymous. This is, in fact, the principle of the celebrated beam interferometer invented by Michelson in 1920 and applied with outstanding success to the measurement of stellar diameters.

The important point to notice is that the resolving power of a stellar interferometer is determined solely by the spacing of the two entrance slits. With given slit separation any subsequent modification of convergence angle by reflection or otherwise affects only the spacing of the fringes and therefore their visibility. It might be possible to apply this principle with advantage to double star interferometers to obtain wider fringes; lower powers could then be used and the method extended to fainter stars.

### Fringes in Heterochromatic Light; Effective Wavelengths

So far we have tacitly assumed starlight to be monochromatic, which is of course very far from the truth. It is necessary to consider the effect of using a mixture of colours, as in the case of white light. For each separate wavelength $\lambda$ there is then a corresponding fringe spacing $\lambda/D$. Figure 6 shows the relative fringe spacing for three wavelengths, designated red, yellow and blue. The central or zero order fringes will be in register, but the other fringes are progressively more and more out of register on either side. The combination of the fringe systems resulting from all the constituent wavelengths will therefore yield an interference pattern in which the fringe visibility falls off rather rapidly on either side of the zero order fringe, and in which the fringe spacing corresponds to an average value of $\lambda$.

Stars differ greatly as regards the proportions of the various colours in the light emitted by them. It is therefore necessary to determine the average value of $\lambda$ or effective wavelength to be used for each spectral type. Strictly speaking, this should also take into account the colour characteristics of the telescope and the observer's eye. For the determination of the effective wavelengths the best procedure is probably

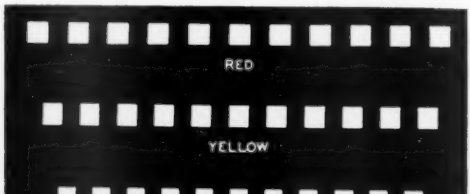



FIGURE 6

micrometer measurement of the widely-spaced fringes given by a grating placed in front of the object glass. Such a grating is merely a compound interferometer consisting of a number of pairs of closely spaced slits.

## VIRTUAL SLITS

With small telescopes it is a comparatively simple matter to place a mask in front of the object glass, rotatable from the eye end. But in the case of large telescopes this is no easy matter. Nor is it necessary.

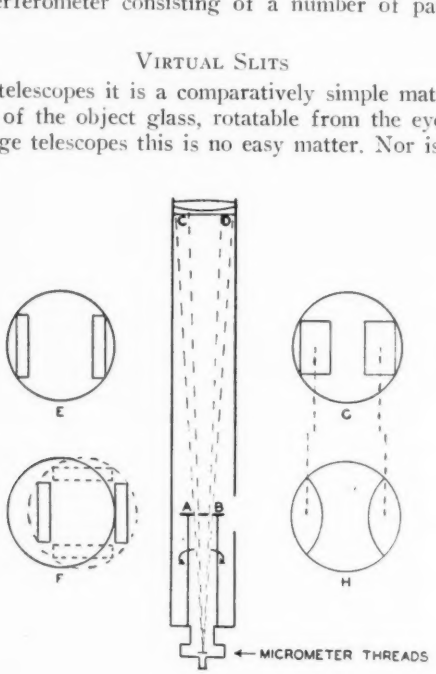



FIGURE 7

The slits can be placed anywhere in the converging cone of rays between the object glass and the focal plane. They could in fact be placed between the eyepiece and the eye. The slits A and B in Figure 7 are equivalent, by projection, to virtual slits C and D on the object glass. It is, of course, important that the virtual slits are wholly on the object glass; at their widest the rim of the glass should be equivalent to a circumscribed circle, as at E. As this must be true in all orientations, it follows that the slits must be symmetrical with respect to the axis of rotation and that the latter must coincide with the telescope's axis of collimation. Failure to achieve this will result in the state of affairs shown at F. The ideal solution is a combined interferometer and micrometer; the cross wires then serve to define the collimation axis and the focal plane from which the slits are projected on to the object glass. A handhole in the side of the tube facilitates insertion or removal of the slits. Errors of collimation and projection are minimised by placing the slit plane as far from the eyepiece as possible.

### Width of Slits

In practice it is not necessary to employ mathematically narrow slits. This is fortunate, as such slits would transmit very little light and that light would be spread over a large diffraction disc. On the other hand, if the slits are too wide their separation, as defined by the distance between their centroids, is considerably less than the maximum possible, with a consequent loss of resolving power. One has to compromise between narrow slits—which give maximum resolving power but transmit little light and spread that light over a large area—and wide slits, which give a lower resolving power but transmit more light and spread that light over a smaller area.

A question that inevitably arises is the validity of the expression $\lambda/2D$ for the resolving power when D is the inter-centroid distance for wide slits. The most thorough mathematical analysis of this question was carried out in 1922 by the present Astronomer Royal, Sir Harold Spencer Jones. He came to the conclusion that no correction for slit width was necessary in the case of interferometer double star measurements made in the usual way.

### Shape of the Slits

It is not necessary or even desirable that the slits should be rectangular in shape. The slits at G and H (Figure 7) have the same area but the inter-centroid distance of the lune slits at H is greater than for the rectangles at G (the dimensions of which have been chosen to give maximum inter-centroid distance for given area).

### Application to Double Star Measurement

Let us now consider briefly how the interferometer is used for measuring close double stars.

A in Figure 8 shows the appearance, on an exaggerated scale, of a

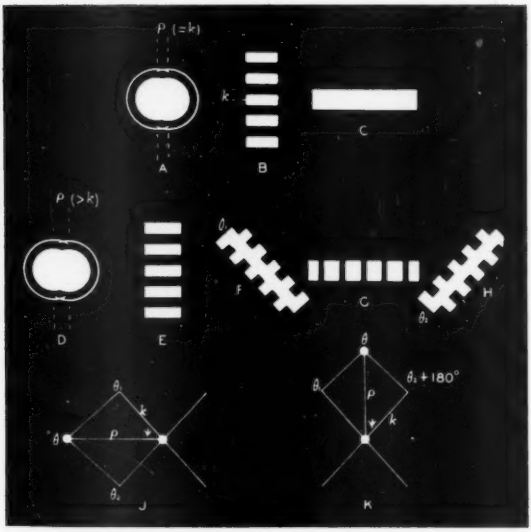



FIGURE 8

close double star with unobscured object glass. The separation $\rho$ of the pair is assumed to be exactly equal to the maximum slit constant $k = \lambda/2D$ which is possible with the given object glass. On bringing these slits into use each star gives rise to a diffraction disc crossed by interference fringes with spacing $2k = \lambda/D$. When the interferometer is oriented as at B we have what is called a "maximum"—the two sets of fringes are in register and so have maximum visibility. On rotating through 90°, however, the bright fringes of one component fall on the dark fringes of the other and we have a "minimum." In this ideal case there are two maxima and two minima in a full revolution, and the position angle of the pair is given by the angle of minimum, and the separation by the slit constant $k = \lambda/2D$.

In most cases the slit constant is not equal to the separation, as at D, where $\rho$ is somewhat greater than $k$. In the orientation E we get a maximum as before. On rotating counter-clockwise to F (position angle $\theta_1$) we get a minimum running through the centre of the fringe pattern, with the extremities of the fringes giving a zigzag effect. At G the dark fringes are again visible but not as prominently as at E; we call this a "secondary maximum." On rotating further we find the zigzag pattern again at H (position angle $\theta_2$), and on rotating through another 180° the whole cycle is repeated.

In actual practice the fringes are usually longer in relation to their separation than indicated in the diagram and one would not expect the

zigzag effect to be very prominent. It is, in fact, easily overlooked and confused with the simple minimum C. (But we shall see later that the zigzag effect, when looked for and recognized, can be turned to very good account.) It is important, therefore, that we do not overlook any of the minima F and H; if only two are noticed at intervals of 180° they will inevitably be interpreted as minima of the type C. The result will be errors in both angle and separation.

When four minima F and H have been observed we find that there is an ambiguity of interpretation, as at J and K.

At J we assume that the position angle $\theta$ is given by

$$\tfrac{1}{2}(\theta_1 + \theta_2)$$

and that the slit constant $k$ equals the projection of the separation $\rho$, i.e.,

$$\rho = k \sec \psi \text{ where } \psi = \tfrac{1}{2}(\theta_2 - \theta_1).$$

At K, on the other hand, we assume $\theta = \tfrac{1}{2}(\theta_1 + \theta_2 + 180°)$ while $\rho = k \sec \psi$ where $\psi = \tfrac{1}{2}(\theta_2 + 180° - \theta_1)$.

The ambiguity can always be resolved by using different slit constants, but a much better way is to note the position angle of the maximum E; this differs from $\theta$ by 90° and is not easily overlooked.

## Historical Summary

The first recorded proposal to use interference methods for astronomical observations was made by Fizeau in 1868, and Stéphan made an early attempt to apply them to the measurement of stellar diameters. But the first serious examination of the possibilities of the method was made by Michelson in 1890, and in the following year he succeeded in measuring the diameters of the four bright satellites of Jupiter with the 12-inch telescope at Mount Hamilton. This work was repeated by Hamy at Paris with very accordant results. Stellar interferometry then languished till 1919 when at Michelson's suggestion Anderson (followed later by Merrill) obtained measurements of the spectroscopic binary Capella (maximum separation 0".05) with the 100-inch reflector at Mount Wilson. A year later Michelson and Pease succeeded in measuring the diameter of Betelgeuse with a 20-foot beam interferometer on the 100-inch—one of the most remarkable feats of observation ever made. This was followed shortly afterwards by diameter measurements of six other stars, including Antares and Aldebaran.

The first systematic application to double star measurement was made by Maggini with the 13-inch refractor at Catania in the years 1922-3. Since that date important lists of interferometer measures have been published by Wilson (18-inch, Flower Observatory, 1934-5) and Jeffers (36-inch, Lick Observatory, 1939-41, 1945). But it is apparent that the method has not been as fully exploited as it might be; observers have probably been discouraged by its apparent difficulty.

## Double Star Interferometry at the Union Observatory

Telescopes are never powerful enough; in the course of our regular

double star work at the Union Observatory we have often felt the need of a greater resolving power than that yielded by our 26½-inch refractor. Accordingly in 1933 I devised a rough and ready interferometer of extreme simplicity in order to test its possibilities. The slits, of thin aluminum, were mounted at the extremity of a draw-tube 21½ cm long. This was a push fit in a second tube, which was arranged to rotate freely in position angle. There was no micrometer or graticule, and the position circle was of cardboard. In order to change the slits the draw-tube had to be removed and then replaced in register with witness marks for preservation of position angle zero and focal setting. In the absence of a graticule to define the collimation axis it was necessary to withdraw the eyepiece frequently during the course of observation and, by placing the eye near the star image, make sure that the slits were properly projected on the object glass. Notwithstanding these difficulties a number of surprisingly good measurements were obtained by Dr. van den Bos and myself. To quote two instances: the binary $\alpha$ Lupi was readily resolved though it had appeared single for some years; a long series of measurements of $\alpha$ Centauri at periastron, when the separation was as low as 0″.13, showed that with bright pairs the method is one of almost text-book simplicity.

In a recent discussion of the accuracy of interferometer measures Baize makes the comment on our observations: "The agreement between micrometer and interferometer is practically perfect."

We felt, however, that the instrument in its experimental form was too inconvenient and uneconomical to be put into regular use. What was needed was a combined instrument so that micrometer or interferometer could be used at will.

Unfortunately the war intervened, and other calls on our time postponed the realisation of this ideal.

### New Interferometer

In 1948 I found time to make a simple but practical interferometer attachment for our Repsold micrometer. As shown in Figure 9, it consists of a light but rigid fabricated aluminium tube, one end of which fits snugly into the micrometer where it can be clamped in position. At the other end is a dowelled removable stage, on which one of the interchangeable slit diaphragms is laid. A convenient hand-hole in the side of the telescope tube provides access to the slits. The slit plane is 604.4 mm above the micrometer threads. Figure 10 shows the interferometer attached to the micrometer.

This arrangement has the additional advantage that diaphragms of other types can be placed on the stage, e.g., iris diaphragm (of great value when measuring faint close companions), hexagon, etc. The inconvenience of placing these diaphragms in front of the object glass has hitherto prevented their full exploitation.

On the other hand, this interferometer did not provide for continuous

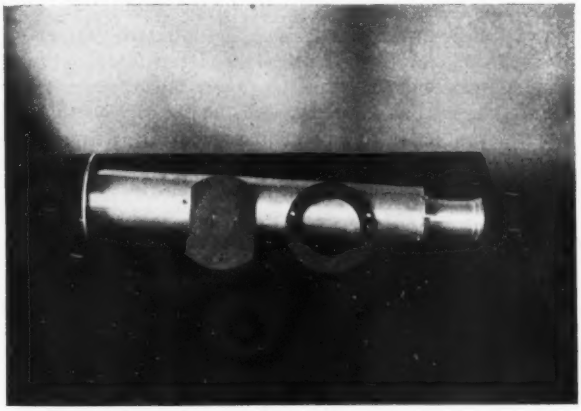


FIGURE 9

variation of slit separation from the eye end. The design of the micrometer does not permit the addition of a control rod for this purpose.

FIGURE 10

Within its limitations the instrument proved quite satisfactory in use, but a little experience soon emphasised the desirability of eye-end control of slit separation. Apart from the loss of time involved in changing slits, continuous variation of resolving power is of advantage in choosing optimum values when measuring by the rotation method. Continuous variation permits also the direct measurement of the separation of double stars.

Figure 11 shows how this problem was successfully solved. The lune-

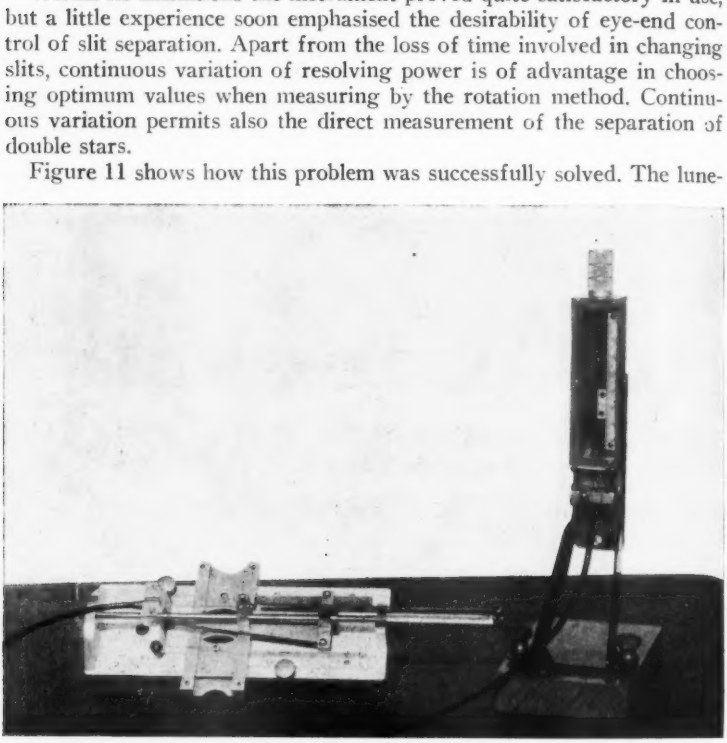


FIGURE 11

shaped slits are cut in two plates moving in slides. A wedge, drawn by a Bowden cable against the pull of a spring, engages studs on the slit plates and moves them symmetrically apart. The cable passes through a hole in the lower end of the telescope tube where it is controlled by a screw of about 5½ mm pitch, provided with index and scale. The cable permits rotation of the micrometer through almost a full revolution. Flexing of the cable introduces a small error, but its effect on the slit constant is reduced by the wedge to a maximum of 0″.002 for $k = 0''.237$, decreasing to 0″.0004 for $k = 0''.099$.

This has proved most satisfactory in use, though there is no denying the fact that the ideal combination of interferometer with micrometer has not yet been achieved.

### EXPERIMENTS WITH ARTIFICIAL DOUBLE STARS

Double star measurement with the interferometer is obviously of an indirect nature, and it is important to be able to interpret correctly the

wide range of possible manifestations presented by various combinations of separation and difference of magnitude. The problem is not made easier by the fact that we see these manifestations as a rule only in the elusive moments of good definition. We must therefore be visually familiar with all possible fringe effects so as to be able to recognise their significance instantly.

One could, of course, rely on acquiring this experience at the telescope. But this would be both tedious and productive of errors, particularly with large instruments. And it is doubtful whether the eligible known doubles are sufficiently representative for the acquirement of the experience necessary in the search for new doubles.

I therefore decided to see what could be learned from a systematic study of artificial double stars in the ideal conditions obtaining in the laboratory.

Figure 12 shows the principle of the laboratory interferometer. The

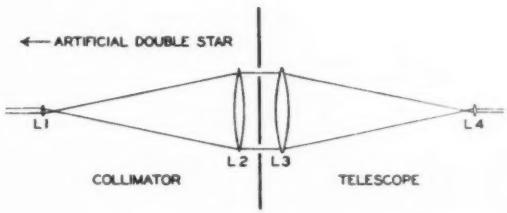



FIGURE 12

artificial double star, placed to the left at a distance of about 35 feet, consists of two apertures in a card placed immediately in front of an electric lamp, thus isolating two parts of the filament. A camera lens $L_1$ of 12.5 mm focal length forms a greatly reduced image of this "double star," which in turn is collimated by lens $L_2$ of 440 mm focal length. Taken together, $L_1$ and $L_2$ may be regarded as a reversed telescope, reducing the angular separation of the double by a factor of 35.2. $L_3$ has an aperture of 27.5 mm and a focal length of 380 mm. The eyepiece $L_4$ has a focal length of 10 mm. The slits are placed between $L_2$ and $L_3$.

At full aperture the resolving power of the telescope is 5″.1; with slits the resolving power can be varied between 2″.4 and 7″.0.

The arrangement may be regarded alternatively as a miniature telescope with object glass of 12.5 mm focal length and eyepiece of 10 mm focal length, with a large aperture erecting system $L_2L_3$ between which the slits are placed.

Figure 13 is a photograph of the apparatus, showing the telescope fitted with a rotating mask containing a central "Tamm" diaphragm and various lune-shaped slits. Another mask with variable rectangular slits is also visible.

Sep. " 7·0
Slit Const. " 7·0
ΔM=0
ΔM=1
7·0 5·0
6·0 6·0
6·0 4·0
4·0 4·0
4·0 3·5
3·2 3·3
3·2 3·0

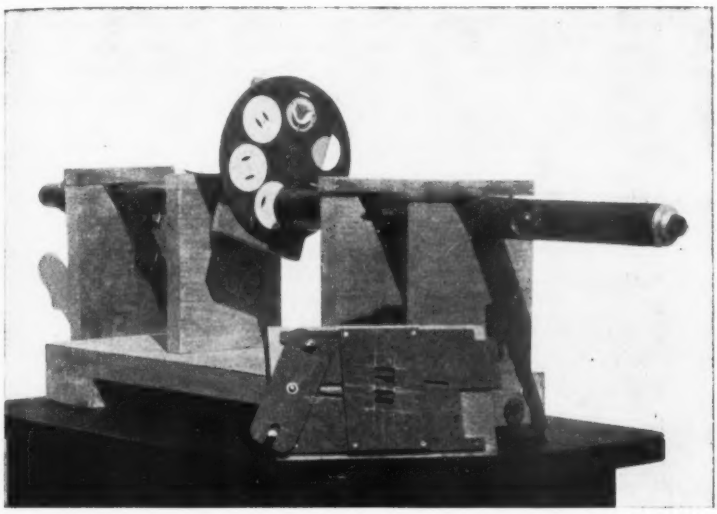


FIGURE 13

With this apparatus a systematic and most profitable study was made of the effects to be seen with double stars having separations varying between 2″ and 7″ (i.e., between 0.4 and 1.4 full aperture resolving power) and differences of magnitude ranging from zero to 1.5. Altogether, some 230 different combinations of separation, difference of magnitude, slit constant and method of measurement were studied and the findings noted. It is of course impossible for me to give a detailed account here; I can only give a very general summary illustrated with a photograph showing some typical interferograms. (See opposite page.)

The two outstanding features are the prominent zigzag effects and the "beaded" nature of the minima. Neither is altogether unexpected.

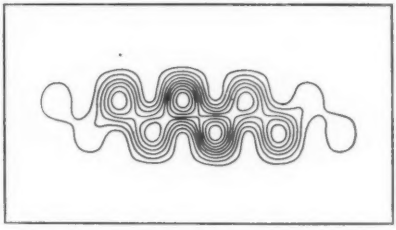


FIGURE 14

Figure 14, in fact, shows theoretical isophotes at intervals of one-tenth of the maximum intensity for a particular case. In 1933 we noticed it

at the telescope and coined the name by which it is now known. We found that the zigzag setting was very critical, the result, no doubt, of the eye's sensitivity for symmetry. In the nearly perfect seeing conditions of the laboratory the zigzag effect was obvious with all but the closest fringe spacings.

As regards the beaded nature of the minima, Figure 15 shows

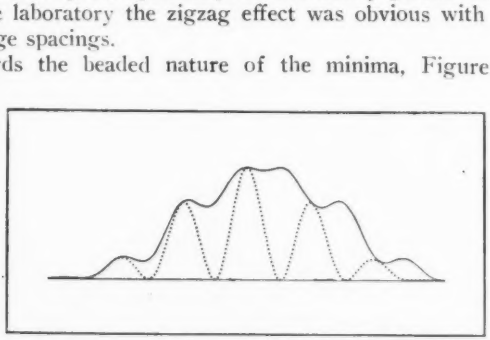


FIGURE 15

(broken line) the theoretical intensity curve of the fringes for slits having a separation three times their width. The full line shows the intensity curve for a minimum, i.e., two equal components separated $\lambda/2D$. It is apparent that the smaller the diffraction disc in relation to the fringes, the more prominent will be the beaded appearance.

It will be noticed on page 414 that a modified zigzag effect is still to be seen when there is considerable difference of magnitude. The bright spikes are now confined mainly to one side of the central minimum; this enables ambiguity of quadrant to be resolved. This modified zigzag effect is often visible, with proper choice of slit constant, when the true minimum (slit constant equal to separation) is almost wholly absent. This is explained by the fact that the fringes of the companion are, in zigzag position, adjacent to the fainter parts of the primary's fringes.

Other important conclusions can be referred to only briefly:

(1). The practical difference of magnitude limit is about 1.0 (for slit constant approximately equal to full aperture resolving power); for the closest pairs it may drop to 0.5 or even 0.0, while for wider pairs it may increase to 1.5 or more.

(2). The separations of equal pairs may be determined either by the rotation method or by variation of slit spacing. In most cases the former procedure is probably preferable. With unequal pairs the rotation method is much more sensitive.

(3). With equal pairs unmistakable partial minima are visible when the separation is about 4/5 of the slit constant. But such partial minima may be indistinguishable from true minima modified by difference of magnitude.

(4). When rotating the interferometer it is important to pay atten-

tion not only to the visibility of the dark fringes, but also to the length of the bright fringes.

### Atmospheric Dispersion

It is well known that at appreciable zenith distances the atmosphere behaves like a prism. In consequence, star images are elongated into short spectra with the red above and the blue below as seen with an inverting telescope. With monochromatic light the effect as regards interferometry would be nil. With heterochromatic light the effect is very serious and it is important to know what precautions are necessary. In Figure 16 we see a star image drawn into a spectrum by atmos-

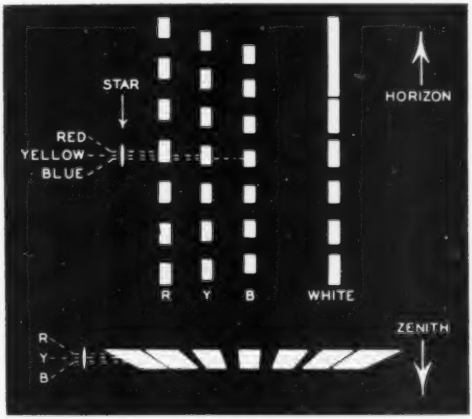



Figure 16

pheric dispersion. Let us consider three wavelengths, designated red, yellow and blue. We may imagine three separate images in these colours, one above the other. Each gives rise to a set of interference fringes, with the zero order fringes also placed one above the other. And, of course, the three sets differ also in the spacing of the fringes.

If, now, we set the interferometer so that the fringe patterns are vertical, as in the upper diagram, the sets combine to form a pattern in white light, with what is apparently the central fringe displaced downwards from its normal position. With increase of zenith distance the visible fringes will move entirely off the diffraction disc.

But if we rotate the interferometer so that the fringe patterns are horizontal, as in the lower diagram, we find that the central fringes in the different colours will be in register vertically, one above the other. The variation in fringe spacing will then result in a fan-shaped appearance.

It seems a convenient convention to define the limiting zenith dis-

tance in any particular case as that for which the apparent central fringe appears on the lowest part of the diffraction disc. On this assumption, and with an appropriate numerical value for the atmospheric dispersion, I obtained the interesting result that the limiting zenith distance z is given by

$$\tan z = 50/a$$

where a is the slit width in millimetres. The limiting zenith distance is thus independent of the separation of the slits, and therefore of the resolving power, but depends solely on the slit width. Here then is another factor to take into account when deciding the question of optimum slit width. And here again the advantage is with the small telescope.

## Eyepiece Interferometer

I remarked earlier that the slits could be placed anywhere in the optical train. Ideally they should be placed in a beam of collimated or parallel rays. The obvious but most inconvenient position is in front of the object glass. Not so obviously they could be placed in the parallel rays between the eyepiece and the eye, preferably in the position of the Ramsden disc. Here we could have a small interferometer consisting of slits and telescope, the large telescope to which it is attached taking the place of the collimator in the laboratory experiments described earlier. The device would, in fact, constitute an interferometer eyepiece, readily brought into use and conveniently in the control of the observer.

I hope to carry out some experiments on these lines in the near future.

## Conclusion

As I have shown earlier, with the simple slit interferometer one may increase the resolving power of a telescope by a factor of nearly 2.44. The gain is in many ways most immediate with small telescopes. Atmospheric effects are less troublesome and the observations may be carried out in almost laboratory conditions. I hope what I have had to say will tempt some of you to try it for yourselves.

Union Observatory, Johannesburg, Union of South Africa.

# A Graphical Representation of Eclipses

By GORDON GRANT

Presented here is a diagram (Figure 1) of the solar and lunar eclipses of the years 1951 through 2000. The day of the year is plotted against successive years. Each horizontal line as marked on the sides of the diagram represents a year, and any vertical line intersects successive years on the same date. Thus every day in the half century is shown on the diagram, disregarding the extra day in leap year. The date on which an eclipse occurs is marked by the center of a circle on the diagram. The type of circle drawn depends on the kind of eclipse. The information for these eclipses came from T. Oppolzer's "Canon der Finsternisse," a comprehensive catalog of eclipses covering a 3,000-year period.

It must be pointed out that this diagram shows eclipses observable from any and all parts of the earth. The number of eclipses observable at a single point on the earth's surface is considerably less. Only a small portion of the earth is completely shadowed during a total eclipse of the sun, and a lunar eclipse is visible over slightly more than half of the earth.

The different types of eclipses are distinguished on the diagram. The headings applied to the following types are identified in the legend at the bottom of the diagram.

TOTAL SOLAR ECLIPSE. An eclipse of the sun occurs when the moon's shadow sweeps over the earth. The portion of the earth covered by the moon's shadow is called the eclipse path. Only within a narrow line along the center of the eclipse path can a solar eclipse be observed as total. On both sides of this central eclipse path the eclipse is observed as partial. When the sun is seen totally covered by the moon throughout the central eclipse path, there is a total solar eclipse. It occurs when the moon is comparatively near to the earth.

ANNULAR SOLAR ECLIPSE. This type of eclipse occurs when the angular diameter of the moon appears to be smaller than that of the sun, due to the greater distance of the moon from the earth. Thus an annulus, or ring, is visible around the moon during the central portion of the eclipse. If the eclipse is annular throughout the eclipse path, it is called an annular eclipse.

CENTRAL SOLAR ECLIPSE. This is a type midway between the total and annular eclipses. It is total along the middle portion of the central eclipse path, but is annular near the beginning and near the end. A central solar eclipse occurs because the surface of the earth presented

to the moon's shadow is curved. Thus only part of the earth is near enough to the moon for the eclipse to be total.

In a broader sense, a central solar eclipse includes total and annular eclipses as well, as distinguished from partial eclipses. Except for the diagram itself, the term will be used in this broader sense throughout the rest of the paper.

PARTIAL SOLAR ECLIPSE. Three degrees of partiality are distinguished depending on the amount of greatest eclipse visible somewhere on the earth. The three degrees are: less than $\frac{1}{3}$, between $\frac{1}{3}$ and $\frac{2}{3}$, and more than $\frac{2}{3}$ of the sun's disc covered. It is shown by the amount of the circle filled in on the diagram. These data were not given by Oppolzer directly, but were computed from a formula involving the distance of the axis of the moon's shadow from the center of the earth, as well as the size of the moon's penumbral shadow.

TOTAL LUNAR ECLIPSE. A lunar eclipse is total when the moon goes entirely within the earth's umbral shadow and is observed as total throughout the half of the earth from which the moon is visible. The less noticeable penumbral lunar eclipses are not considered in this paper since Oppolzer does not list them in his regular eclipse tables.

PARTIAL LUNAR ECLIPSE. When only part of the moon enters the earth's umbral shadow, there is a partial lunar eclipse. The three degrees of greatest eclipse are distinguished as in the partial solar eclipses. This information was obtained easily from Oppolzer, as he gives the distance of the center of the moon from the center of the earth's shadow at the time of greatest eclipse.

Figure 1 shows immediately that the eclipses plotted in the manner suggested do not appear at random, but are arranged in orderly fashion, both as to position and type of eclipse. It is the purpose of this paper to explain these regularities and to show how they demonstrate many of the variable factors involved in an eclipse. The following explanation is intended to show in a simple fashion some of the phenomena of eclipses. (See Figure 1 following page 422.)

To facilitate discussion of these recurrences, the durations of the various periodic motions of the moon and the earth are shown in Table 1.

TABLE 1

| *Period* | *Duration* |
|---|---|
| | d |
| Synodic month | 29.5306 |
| Nodical month | 27.2122 |
| Anomalistic month | 27.5545 |
| Eclipse year | 346.620 |
| Tropical year | 365.242 |

TABLE 2

| *Period* | *Duration* |
|---|---|
| | d |
| 223 Synodic months | 6585.32 |
| 242 Nodical months | 6585.36 |
| 239 Anomalistic months | 6585.54 |
| 19 Eclipse years | 6585.78 |
| 18 Tropical years | 6574.36 |

All the periods in the table are expressed in mean solar days. A synodic month is the period of revolution of the moon in its orbit with respect to the sun. The period from new moon to new moon is one synodic

month. A nodical month is one lunar revolution with respect to the moon's node. It is shorter than the synodic month mainly because of the forward motion of the sun, but also slightly because of the retrograde motion of the nodes. An anomalistic month is the time necessary for the moon to return to the same place in its orbit, for instance, from apogee to apogee. An eclipse year is the time it takes for the sun to return to the same node of the moon's orbit. It is shorter than the tropical year because of the retrograde motion of the line of nodes. A tropical year is the interval between two successive returns of the sun to the same right ascension on the celestial sphere. The calendar year is the closest approximation to the tropical year.

The various combinations of the periodic motions which closely approximate a saros period appear in Table 2. A saros period is defined as 223 synodic months. Further details of this will be discussed later.

Examples of these periodicities are shown in Figure 1 by straight lines running through a sequence. (A) is the line of eclipses, caused by the position of the moon's node. (B) is the line of new moons, marking a period of twelve synodic months. (C) is the line of moon's apogee, caused by the revolution of the moon's orbit. Annular eclipses will occur approximately on these dates. (D) is the line of saros, important in the study of the recurrence of eclipses. Each of these lines will be discussed in turn.

### (A) Line of Eclipses

If the plane of the moon's orbit were the same as the plane of the ecliptic (the plane of the orbit of revolution of the earth in which the sun appears to move), there would be an eclipse of both the sun and the moon every month, at new moon and full moon, respectively. However, this is not the case. The plane of the moon's orbit is inclined about 5° 8′ to the ecliptic, so eclipses can be expected only when the sun and the moon are near the intersection of the two planes. This intersection is called the line of nodes, and passes through the center of the earth. The direction of this line defines two points on the celestial sphere which are the nodes, situated on opposite sides of the sky, 180° apart on the ecliptic. Thus eclipses can occur only during two periods of the year, that is, when the sun is near one of the nodes on its apparent annual path along the ecliptic. These periods are known as the eclipse seasons. By looking along the horizontal lines, each of which represents a tropical year, the two eclipse seasons are readily apparent. Occasionally there are portions of three eclipse seasons in a tropical year. The total number of eclipses in a year may be readily determined by looking along the horizontal lines.

The plane of the moon's orbit does not remain fixed in space, but rotates in a retrograde direction with a period of 18.61 years. Thus the node moves westward 19°.34 in a tropical year. If the sun appears at a node, it will reappear at the same node after an eclipse year, which consists of two seasons and is 18.62 days less than a tropical year. Line

(A) is a line of eclipses, and it intersects successive years 18.62 days earlier than the previous year. Several of these lines could have been drawn in the diagram.

It is not sufficient for the sun to be near a node; the moon must be there also. To indicate how near, the term "ecliptic limit" is utilized, which is defined as the greatest angular distance of the sun from the node along the ecliptic at which an eclipse is possible. This definition also applies to lunar eclipses, as the earth's shadow is always 180° from the sun.

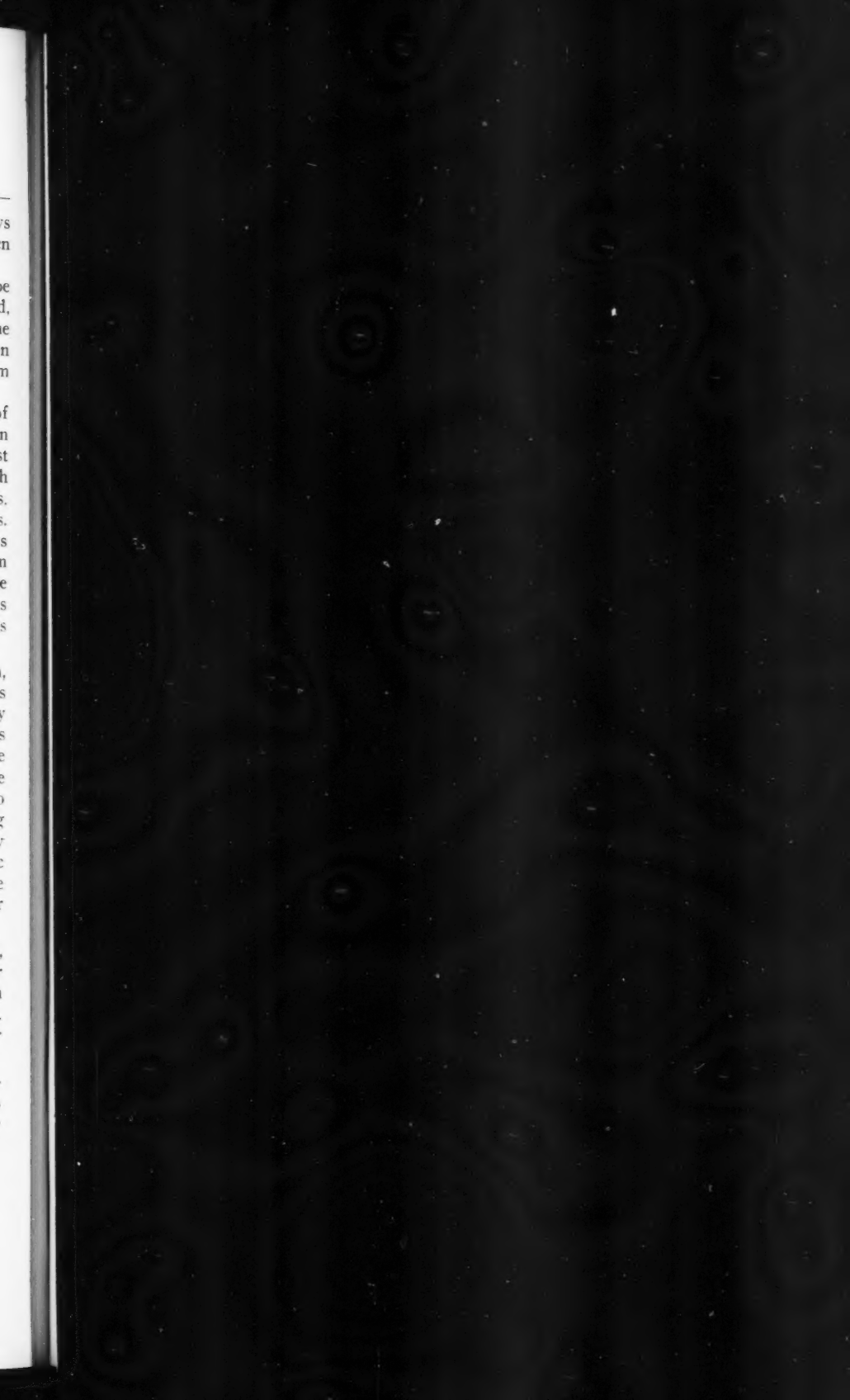
The ecliptic limit depends on three factors: the angular diameter of the moon, the angular diameter of the sun, and the angle of inclination of the moon's orbit. None of these three factors are constant; the first two vary considerably because of the eccentricity of the orbits of both the moon and the earth, and the third only slightly, due to perturbations. Thus two limits are recognized: the major and the minor ecliptic limits. If at the time of new moon, the sun (and therefore also the moon) is outside the major ecliptic limits, an eclipse is impossible. In between these two limits, an eclipse may or may not occur, depending on the three variables just mentioned. The probability for an eclipse increases as the minor limit is approached from the major limit. If the sun is within the minor ecliptic limit, an eclipse will inevitably occur.

By noticing the number of solar eclipses per year in the diagram, their frequency can be interpreted in terms of ecliptic limits. There is always at least one solar eclipse during an eclipse season. Occasionally there are two, but never more than that. The reasons for that are as follows. The major and minor ecliptic limits for solar eclipses are 18° 31′ and 15° 21′ from the node, respectively. As the motion of the sun is slightly less than 1° daily, it will take the sun at least 30 days to traverse the distance between the ecliptic limits preceding and following the node. Since this is longer than a synodic month, at least one new moon must occur during the time the sun is within the minor ecliptic limits, thus causing a solar eclipse. Two solar eclipses in an eclipse season occur occasionally, taking place near the ecliptic limits on either side of the node.

For central solar eclipses, the ecliptic limits are 11° 50′ and 9° 55′, and the average limits are 10° 52′. Since the sun is within the major central solar ecliptic limits for less than a synodic month, there can never be more than one central solar eclipse during an eclipse season. It is possible for an eclipse season to go by without a central solar eclipse.

The major and minor lunar ecliptic limits are 12° 15′ and 9° 30′, respectively. The average is about 10° 52′. This is the same situation as in central solar eclipses. There can never be more than one lunar eclipse during an eclipse season, and an eclipse season can go by without any lunar eclipses. This fact is observed on the diagram.

That these two sets of ecliptic limits are the same is not coincidental.



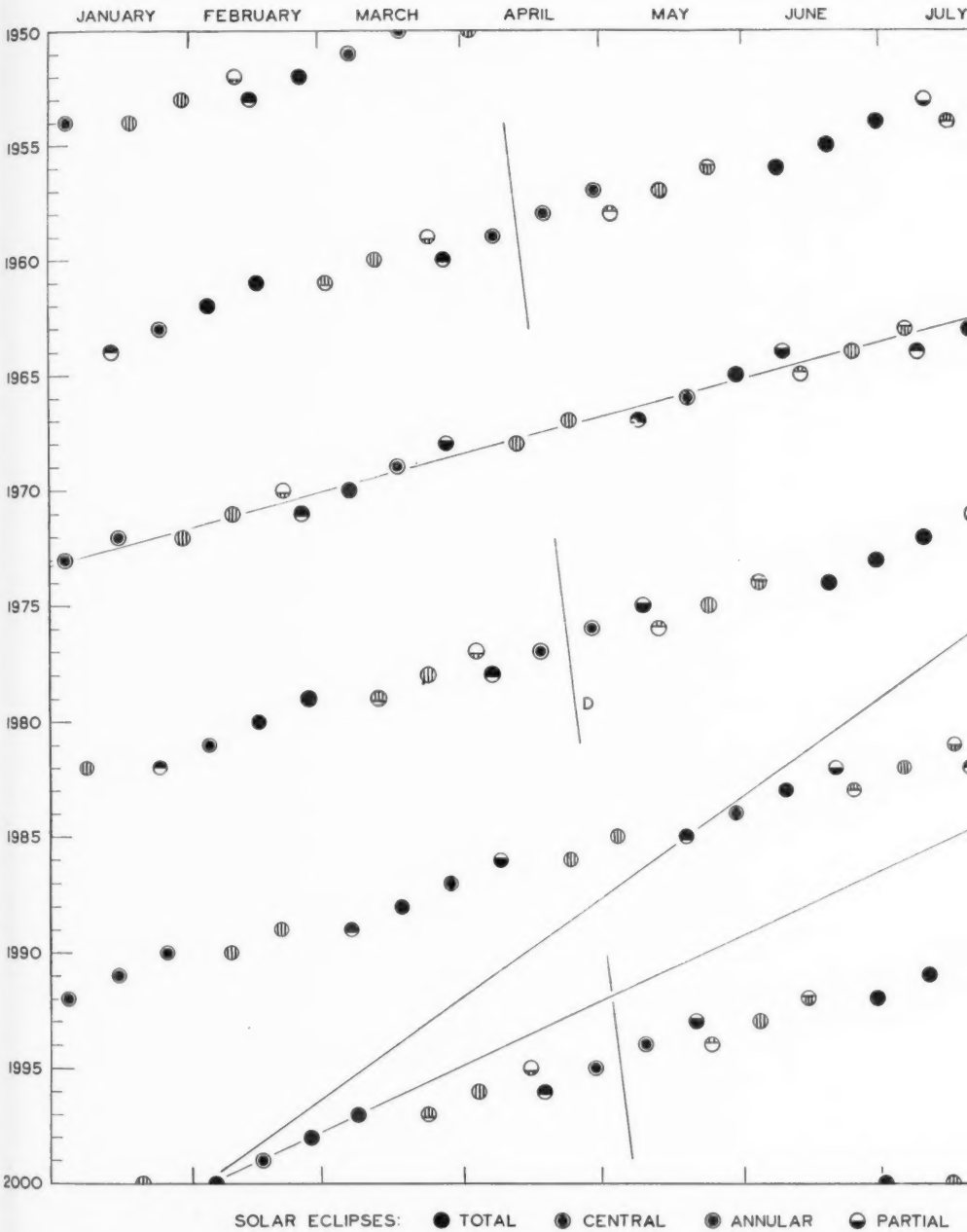

JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
D
SOLAR ECLIPSES: TOTAL CENTRAL ANNULAR PARTIAL

FIGURE 1

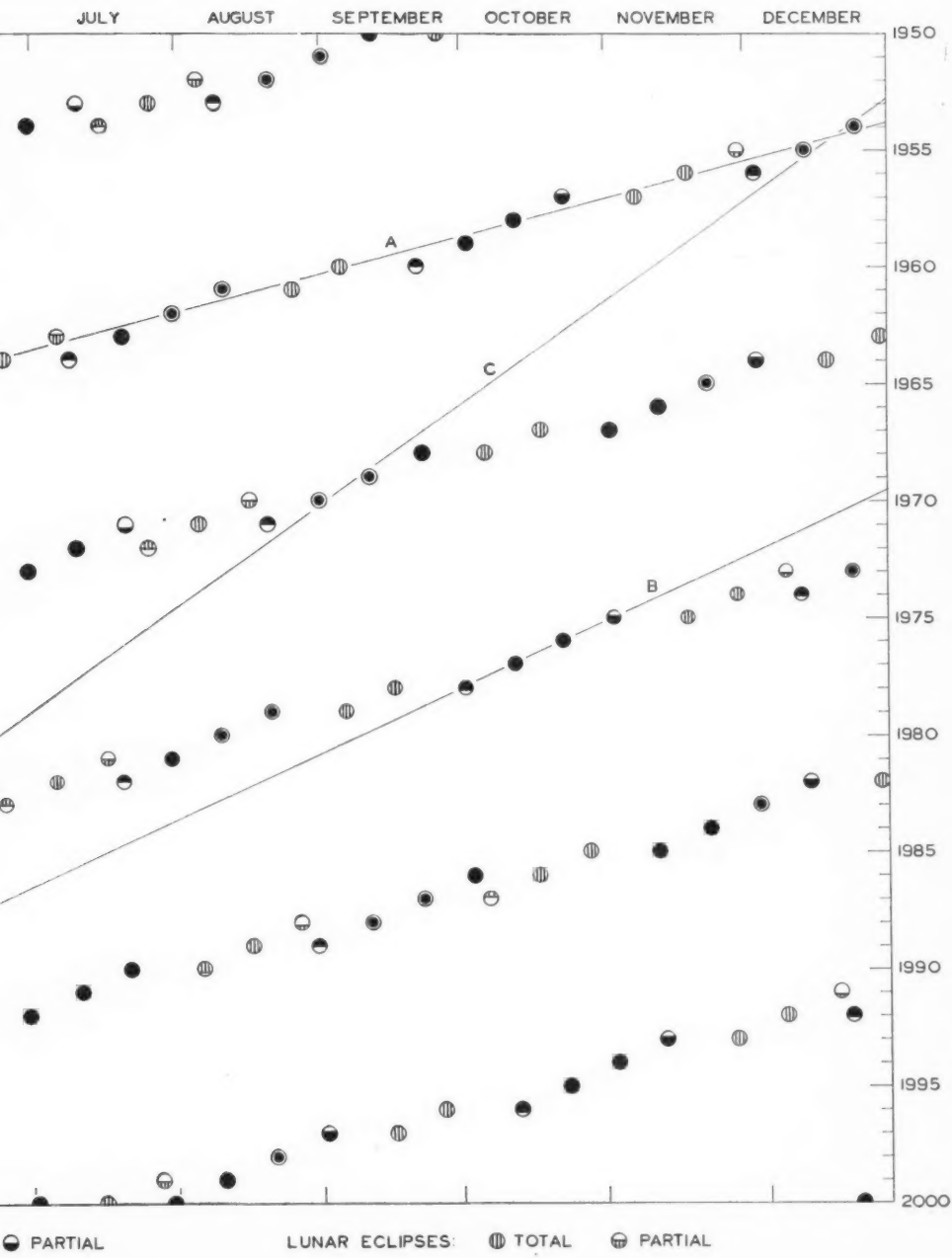

JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
A
B
C
PARTIAL
LUNAR ECLIPSES:
TOTAL
PARTIAL

FIGURE 1

Because of the great distance of the sun from the earth-moon system, lines from one side of the sun tangent to opposite sides of the earth are practically parallel. If both sets of lines are drawn, from opposite sides of the sun, the lines associated with the conventional diagram of the sun-earth-moon system during an eclipse appear. The lines converging from the earth in both directions form the umbral shadow behind it and an imaginary cone in front of it, of practically the same dimensions. The full moon has to enter the umbral shadow for a lunar eclipse to occur, while the new moon has to enter this imaginary cone for a central solar eclipse to occur. Thus the ecliptic limits are practically equal. It can be shown in a similar way that the ecliptic limits for partial solar eclipses are almost the same as the penumbral lunar ecliptic limits.

It has been shown that the maximum number of solar eclipses in an eclipse season is two, one near the limits on either side of the node. If this is the case, there must necessarily be a lunar eclipse between these two solar eclipses. It will be total, because in this case the sun is very close to the node at the time of full moon. Therefore the maximum number of all eclipses in an eclipse season is three, two solar and one lunar. Since there are two eclipse seasons, six eclipses are possible in an eclipse year. If the eclipse seasons are near the beginning or the end of a tropical year, the shorter length of the eclipse year as compared with the tropical year allows one more eclipse. It may be either solar or lunar. Thus the maximum number of eclipses in a tropical year is seven, either five solar and two lunar or four solar and three lunar. There are no examples of the former in this half century, but the latter arises in 1982.

The most probable number of eclipses in a tropical year is three or four. At least two of these are solar, and the other one or two are usually lunar. Since at least one solar eclipse must occur during each eclipse season, the minimum number of eclipses in a tropical year is two, one solar eclipse during each eclipse season. These are central eclipses because they must occur near the node, in order that the following and preceding full moons fall outside the ecliptic limits.

### (B) Line of New Moons

As can be calculated from Table 1, 12 synodic months are 354.37 days long, which is 10.87 days less than a tropical year. Line (B) intersects each successive year 10.87 days earlier than the previous year, thus meeting a new moon. Lines parallel to (B) could be drawn a synodic month apart through all series of solar eclipses, and, in between, lines of full moons could be drawn.

Twelve synodic months are 7.75 days longer than an eclipse year. If a solar eclipse occurs at a node one year, there will be an eclipse twelve synodic months later, and it will occur 7.75 days after the mean sun passes the node. An eclipse is possible twelve synodic months after that, though the new moon is usually outside the ecliptic limits. Working backwards, there would have been an eclipse twelve synodic months be-

fore coming to the node, and possibly one the preceding year. Thus if an eclipse occurs at a node, then three or five eclipses may occur in the series. In practically all cases however, there are four solar eclipses in a series, two on each side of the node. This series is defined as the synodic series, as the synodic period of the moon is the predominating factor. There is only one case of three solar eclipses in a synodic series and no cases of five eclipses in a series in this fifty-year period, though there were several cases of the latter in the previous half century. The central solar eclipse limits are also evident, as there are usually two and never more than three central solar eclipses in a synodic series. Any partial solar eclipses will fall either at the beginning or at the end of a synodic series.

As the lunar ecliptic limits are smaller than the solar limits, a line of full moons would be expected to show fewer eclipses in a synodic series than the line of new moons. Figure 1 shows this to be true. However, the diagram shows about the same number of lunar eclipses in a synodic series as central solar eclipses in a series. This is to be expected, as the ecliptic limits have the same average value. There will never be less than two nor more than three lunar eclipses in a synodic series.

### (C) Line of Moon's Apogee

Thirteen anomalistic months, as can be found from Table 1, total 358.21 days. This is 7.03 days shorter than a tropical year, so if the moon is at apogee at a given date one year, it will be at apogee 7.03 days earlier the following year. Line (C) connects these successive dates of the moon's apogee. It passes through several series of annular eclipses, which is to be expected, since at apogee the moon is farthest from the earth. Similar lines drawn parallel to line (C), an anomalistic month apart, would connect other dates of apogee.

### (D) Line of Saros

This is the most interesting feature in the diagram. It indicates the recurrence of eclipses after 223 synodic months. This is defined as the saros period, which Table 2 shows to be 6585.32 days long. It is 18 years and 10⅓ or 11⅓ days long, depending on the number of leap years in the interim. All through the diagram it will be noted that the same types and degrees of eclipses are repeated after a saros period. Since single eclipses recur in practically the same fashion, the synodic series will repeat themselves as well. Line (D) runs through repeated solar synodic series. It is not drawn continuously because of the interference at the half saros with a lunar synodic series.

Clearly there is an explanation for these recurrences, and Table 2 gives the answer. After a saros period, the sun and the moon will be in practically the same position with respect to the node, for both a whole number of nodical months and eclipse years have elapsed. There are no other combinations of these periods which coincide so closely in a relatively short period of time. Both the apparent sun and the moon are

moving in the same direction with respect to the stars. After a saros period, the number of synodic months (223), each of which is a conjunction of the sun and moon, will be the difference of the numbers of elapsed nodical months (242) and eclipse years (19). The 223 synodic months are exactly one saros period, since eclipses must recur after a whole number of synodic months. Another factor adding to the similarity of these recurring eclipses is that the saros period is also very close to a whole number of anomalistic months. Thus the moon will be very close to the same place in its orbit after a saros period has elapsed, making its apparent angular diameter very nearly the same. A saros period is only 11 days longer than 18 anomalistic years, which is the time that it takes the earth to travel from perihelion to perihelion in its orbit. Thus both the lunar distance and the solar distance will be close to the same value after a saros period. In practically all respects, the factors that cause an eclipse are very nearly the same after a saros period has elapsed.

Although conditions for an eclipse are practically the same after a saros period, it is seen that this is not exactly the case. A saros period is not exactly as long as a whole number of nodical months or eclipse years. For simplicity, the effects of these slight differences can be demonstrated by assuming a total lunar eclipse with both the sun and the moon exactly at the node, with the moon at apogee, and examining the situation one saros period later. After 223 synodic months, there will again be a full moon and there will be an eclipse. Table 2 shows that the moon has not quite reached the node, requiring .04 days to get there. The moon's angular motion is about 13° per day, while the motion of the sun (and the earth's shadow) is about 1°. So the motion of the moon with respect to the sun is 12° daily. In .04 days, the moon will travel 29′. Thus the eclipse will already have occurred .04 days earlier and 29′ west of the node in longitude.

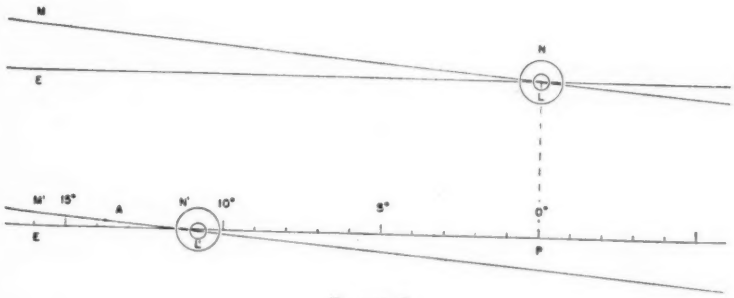



FIGURE 2

This can be shown in another way, with the aid of Figure 2. The upper part of the diagram shows an eclipse of the moon with both the

sun and the moon at the node. For convenience, this point is taken at 0° longitude. The moon moves along in its orbit M eastward to the left, and the earth's shadow travels in the same direction along the ecliptic E. They intersect at the node N, and there is an eclipse L. The smaller circle is the moon, and the larger is the earth's shadow. This is also a special case where the moon is at apogee. The lower part of the diagram shows the situation exactly one saros period later. The horizontal line is again the ecliptic E, but the moon travels along M′. The intersection is at the node N′ but the eclipse L′ has already occurred. The point of lunar apogee A has not yet occurred at the time of the eclipse. The explanation is as follows.

After 18 tropical years have passed, the sun will again be at the same longitude, so the earth's shadow will be directly below, at point P on the diagram, Figure 2. As Table 2 shows, the saros occurs 10.96 days later, and during this time the shadow travels 10° 49′ eastward to get there. It is here at L′ that the eclipse occurs. This, however, is the same motion as that of the mean sun, which is an average motion. As the earth is nearer to the sun in January, it moves faster in its orbit. In 10.96 days, it moves 11° 12′, which is the same motion of the apparent sun, and also of the earth's shadow. In July, near aphelion, the earth moves more slowly than average, traveling only 10° 30′ in the 10.96 day period. This is an influence of the earth's orbital eccentricity.

The period of revolution of the moon's nodes is 18.62 years, or 0.58 years longer than the saros. Almost one revolution will have been made then after a saros, in a retrograde direction. As the annual nodal motion is 19° 34′, in 0.58 years the line of nodes, N′, will be found 11° 18′ east of its former position. Remembering that the earth's shadow is 10° 49′ to the east of its former position on the average, it is seen that the eclipse will occur 29′ west of the node (N′ — L′). This agrees with the value as found by the other method. However, it is seen by comparison with the values of the solar motion in January and July that an eclipse in January will occur only 6′ west of the node, but 48′ west in July.

As 239 anomalistic months are only 0.22 days longer than a saros period, in this special case, the moon will return to apogee after 0.22 days. During this time the moon has traveled 2° 54′ and will also be 2° 26′ east of the node. This is point A.

Because of the eclipse occurring 29′ west of the node after a saros, by the time several saros periods have gone by the full moon will take place so far west of the node as to be outside of the ecliptic limits. At a previous time the full moon must have entered within the ecliptic limits. Remembering that twice the solar ecliptic limits are about 32°, it is seen that an entire saros sequence will last about 70 saros periods, or 1,260 years. Because the shift in longitude is 11° toward the east for each saros, a whole saros sequence will make a circuit of the ecliptic more than twice.

It is interesting to observe the changes in a saros sequence of solar eclipses. The series begins with partial eclipses, the penumbra of the moon's shadow grazing one of the poles of the earth. As the difference between the solar ecliptic limit and the central solar ecliptic limit is 6°, there will be about 12 partial eclipses of the sun in this sequence before a central eclipse appears. There will be about 40 or 50 central solar eclipses in a sequence. The central sequence begins when the axis of the moon's shadow touches the earth at one of the polar regions. Successive solar eclipses appear nearer to the equatorial regions, and the end of the series comes when the axis of the moon's shadow leaves the earth at the other pole. After 10 or 12 more partial eclipses, this particular saros sequence is concluded. The pole at which a sequence begins depends on whether the eclipse occurs at the ascending or the descending lunar node.

As the ecliptic limits for umbral lunar eclipses are smaller than those of solar eclipses, a saros sequence of lunar eclipses will be of shorter duration. There will be a total of about 48 eclipses in sequence: 13 partial eclipses at the beginning of the series, 22 total eclipses in the middle, and 13 partial eclipses at the end of the sequence. The whole sequence covers about 865 years.

Returning now to an eclipse after a saros, it was seen that the position of the eclipse with respect to the node deviates to a great extent from its average value of 29′, amounting to only 6′ in January and 48′ in July. Thus eclipses occurring in winter show exceedingly small changes in successive saros periods. On the other hand, eclipses occurring in the summer months show much greater changes over several saros periods. It will be noted on the original diagram that there are many more cases of eclipses changing in degree after a saros in midyear than at the beginning or the end of the year.

In light of this variation in change depending on the time of the year that the eclipse occurs, one might be led to believe that the general trend of eclipses would be toward the end of the year, for as the eclipses would be shifting west in longitude quite extensively during the summer months, in the winter there would be practically no shift at all. This would lead to an increase in the eclipses in the latter part of the year, with a corresponding decrease in summer eclipses, were it not for the fact that eclipses in successive saros periods occur 11° east in longitude. Over a period of 32 saros, a given sequence will have completely made the circuit of the ecliptic, and eclipses will have been found in all seasons. The slight change in the position of succeeding eclipses with respect to the node is negligible in comparison with the 11° shift of the node on the ecliptic. Thus it is justifiable to use the average value of 29′ for the change after a saros for computing the length of a saros sequence.

As a conclusion, a statistical summary of the different types of

eclipses and their relative abundances for the period 1951 to 2000 is shown below. An analysis follows the table.

TABLE 3. ECLIPSES FOR THE YEARS 1951-2000

| *Solar Eclipses:* | | *Lunar Eclipses:* | |
|---|---|---|---|
| Total | 35 | Total | 43 |
| Central | 3 | Partial | 29 |
| Annular | 34 | | |
| | — | Sum | 72 |
| All Central Solar Eclipses | 72 | | |
| Partial | 39 | | |
| Sum | 111 | Grand Total | 183 |

As the central solar ecliptic limits are very close to the lunar ecliptic limits, an approximately equal number of these two types of eclipses would be expected. In this half century, they happen to be exactly the same. The ratio of central solar eclipses to all solar eclipses agrees with the corresponding ecliptic limits. The former is 72 to 111 or 1:1.54, and the latter is 10°.8 to 16°.9 or 1:1.55. Ratios between other types of ecliptic limits show the same agreement.

This table implies that there are about an equal number of annular and total solar eclipses, but counts over a longer period of time show a slight excess of annular eclipses. This is because the average length of the moon's shadow is 232,000 miles while the average distance from the earth to the moon is 238,000 miles, varying from 221,000 to 252,000 miles. The moon's distance must be less than 232,000 miles for a solar eclipse to be total, as the tip of the moon's shadow must touch the earth in this case. Fifty years is actually not a long enough period of time to form any general conclusions regarding the relative numbers of different types of eclipses, but it is sufficiently long to show that the numbers are consistent with the various ecliptic limits.

I especially want to thank Dr. L. Binnendijk, Director of Goodsell Observatory, who suggested this diagram in the beginning and who has given valuable aid throughout the preparation of the diagram and the manuscript. I also want to acknowledge the assistance of the late Dr. C. H. Gingrich, former editor of POPULAR ASTRONOMY, whose suggestion it was to publish this diagram and paper, and Dr. E. W. Woolard of the U. S. Naval Observatory who helped solve a mathematical difficulty.

GOODSELL OBSERVATORY, CARLETON COLLEGE, NORTHFIELD, MINNESOTA,
JULY, 1951.

# Contributions of the Meteoritical Society

**Edited by FREDERICK C. LEONARD**
**Department of Astronomy, University of California, Los Angeles 24**

## The Achilles, Rawlins County, Kansas, Chondrite (ECN = + 1008,398)

H. O. STOCKWELL
P. O. Box 563, Hutchinson, Kansas
*and*
RUSSELL A. MORLEY
399 North 18th Street, Salem, Oregon

ABSTRACT

The discovery of the Achilles, Rawlins County, Kansas, meteorite (ECN = + 1008,398; cl. = veined crystalline chondrite, Cka) was made by the Homedale brothers in 1924. The meteorite remained unrecognized for 26 years, until Mr. Anthony Halner noticed the similarity between it and specimens in the H. O. Stockwell display at the Kansas State Fair. The meteorite weighs 12,020 gm. and is covered by a fusion-crust. The original weight is estimated as 16 kg. The meteorite is preserved in the collection of Mr. Stockwell.

The Achilles aerolite was first mentioned on September 20, 1950, as a possible meteorite by Mr. Anthony Halner, of Herdon, Rawlins County, Kansas. Mr. Halner became interested in the similarity between a heavy rock he had seen some years before, when he was painting on the Homedale ranch, and the specimens in the H. O. Stockwell display of meteorites at the Kansas State Fair at Hutchinson. After telling Mr. Stockwell of his possible find, arrangements were made to visit the location and to obtain samples of the suspected meteorite for verification.

The Achilles meteorite was found in 1924 by Mr. Erick Homedale on the Homedale farm, 4 miles north of the town of Achilles, Rawlins County, Kansas, which is located in the S. E. ¼ of Sec. 22, T 17, R 26 W. The longitude of the place of find is approximately W. 100° 48′ 48″ and the latitude is N. 39° 46′ 36″. This location has the equatorial coördinate number (ECN), + 1008,398. The discovery was made on the east slope of a rise not far from a private road, where, some 3 years before, the rock had been noticed projecting above the prairie sod. One day following a rain that had interrupted the wheat harvest, the Homedale brothers decided to investigate the odd, brown-and-black, mottled rock, which they had passed many times in the course of years and to which they had paid little or no attention. The area, being practically devoid of rocks, made such an object more conspicuous than it would otherwise have been. They carried the strange-looking rock to their house, where, over a period of years, a considerable amount of material

was broken off of it and carried away by curious visitors. The meteorite was to remain unrecognized for 26 years, until its existence was brought to the attention of Mr. Stockwell, during a visit from Mr. Halner, who was attending the Kansas State Fair, where Mr. Stockwell had on exhibition his collection of meteorites. The meteorite was subsequently purchased from the Homedale brothers by Mr. Stockwell, and may now be viewed in his cabinet of meteorites. This meteorite has the distinction of being the second such specimen recovered from Rawlins County, Kansas; the other recovered meteorite is known as the Beardsley aerolite (ECN = + 1012,398; cl. = gray chondrite, Cg), which was recovered some 23.8 miles to the northwest of the location of the Achilles stone.

The Achilles specimen is entirely covered, with the exception of the fractured surfaces, by a mottled, black-and-brown fusion-crust. The meteorite weighs at present 12,020 gm., and gives every evidence of having weighed in its entirety close to 16 kg. It is roughly hexagonal in form, with the thickness tapering sufficiently to give it a blunt wedge-shape when viewed from the end. The overall dimensions are as follows: length, 26.9 cm.; width, 24.7 cm.; thickness, 14.5 cm. The specific gravity, as determined by aid of a precision Jolly balance, is 3.40, at 21° C.

The following data are based upon observations made from a slice measuring 47.6 mm. × 3.52 mm. × 3.7 mm. and weighing 19.3 gm. The meteorite is a veined crystalline chondrite (Cka). The specimen is well traversed by a network of fine veins. Nickel-iron is fairly abundant and evenly distributed thruout the mass. The slice shows a number of frac-

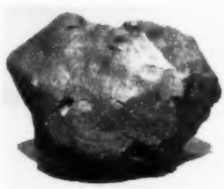


FIG. 1
THE ACHILLES CHONDRITE

ture lines, and, in a few cases, their widening appears to have been augmented by the leaching effect of ground water that gained entrance from those fractures that connect with the exterior surface. One very large chondrus, which is only partly preserved because of breakage along the outer periphery, is 5.4 mm. in diameter.

# The Aba, Japan, Aerolite: A Recent Meteoritic Fall that Injured a Human Being*

## PART I: ON A RARE EXAMPLE OF METEORITIC FALL

ISSEI YAMAMOTO
Kwasan Observatory, Kyoto University, Kyoto, Japan

Translated by S. Murayama from the Japanese Journal, *The Heavens*, **8**, No. 84, 1928

On January 12, 1928, I received a letter from Mr. Seiichi Yanagimachi, the president of the primary school in Aba-mura, Inashiki-gun, Ibaragi-ken, inclosing a small specimen of meteorite. The letter, conveying news in which I was much interested, read as follows:

"The inclosed specimen of meteorite fell on Mr. Tahei Kuriyama's property in our village at about 9 A.M., April 28, 1927. At that time his second daughter who was 5 [3½?] years old was playing in the garden, when, to her mother's astonishment, she suddenly cried out. Her mother found that she had suffered head injuries in two places and that a small piece of stone had come to rest on her neck-band. The meteorite is reported to have been hot at first. Fortunately the girl recovered after several days . . ."

A large number of meteor[ite]s fall into our atmosphere every day, and the number of meteorites that reach the Earth is not insignificant; in fact, nearly a hundred specimens of meteorites have been found in Japan, and perhaps more than a thousand [about 1500 in 1951] have been recovered thruout the entire world. Because of this fact, we are often asked whether there is any chance of being hit by a meteorite, but we have not been able to find any record of such an accident in the past. This fact is not surprising when we compare the smallness of our [own] bodies with the vastness of the entire surface of our Earth. Since it was so unprecedented, the recent accident in Ibaragi-ken was of the greatest interest, and I immediately showed the information I had received to my colleagues.

The small piece of stone inclosed in the letter is certainly an actual meteorite, with a common fusion-crust; it is about $7.5 \times 5 \times 3$ mm., weighs only 0.19 gm., and has a specific gravity of about 3. I think that this is one of the smallest individual meteorites ever to have fallen to the Earth—a very fortunate fact, for otherwise a terrible accident might have resulted.

In answer to my further questioning, Mr. Yanagimachi kindly reported: (*a*) that the name of the girl hit by the meteorite is Chyu Kuriyama (born October 26, 1923); (*b*) that her mother's name is Teru Kuriyama (then 28 years old); (*c*) that no sound was heard when the

*Communicated by Lincoln LaPaz and read by title at the 14th Meeting of the Society, Los Angeles, California, 1951 June 18-19.

meteorite fell; (*d*) that no other piece of meteorite was recovered in the vicinity; and (*e*) that the meteorite was brought to the school on April 30, [1927,] and kept thereafter by Mr. Yanagimachi until he sent it to me. Mr. Yanagimachi included also a plan of the Kuriyama establishment, but this is omitted from the present note.

I have named the specimen in question "the Aba meteorite," and intend to introduce it to scientists in this country and abroad.

## PART II: COMMENTS ON THE ABA METEORITIC FALL

S. Murayama

The National Science Museum, Tokyo, Japan

Recently (1951) I have had an opportunity to see the specimen of the "Aba" meteorite. It is a small piece of stone (Fig. 1). About half

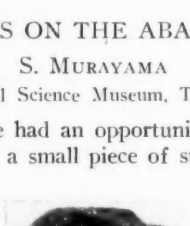


Fig. 1

The Aba, Japan, Aerolite (×4)

of its exterior is black, whereas the other half shows a broken surface of a brownish color. The black surface seems to be the "fused crust," but, in my opinion, there is some doubt as to the reality of the stone's meteoritic origin, for it is non-magnetic and contains no nickel-iron grains, altho there are some rusty-looking spots, probably of iron oxide. At any rate, this specimen does not belong to the typical class of meteoritic stones.† There are, however, some facts that support the meteoritic origin of the specimen; *e.g.*, as Dr. Yamamoto has pointed out (*ante*), the stone had so much kinetic energy that it injured a girl's head by its impact. So small a stone could not have had such high speed under ordinary conditions. Furthermore, neither any active volcanoes nor any industrial plants are situated in the locality where the Aba specimen fell.

Thru the kind offices of Dr. Yamamoto, the Aba stone has just been loaned to me for further study. An investigation of this tiny but interesting specimen will be carried out and reported on in a later note.

†[But it *might* be a calcium-rich, non-ferriferous achondrite (subclass $A_1$). —F.C.L.]

# Injuries from Falling Meteorites

LINCOLN LAPAZ
Institute of Meteoritics, University of New Mexico, Albuquerque

ABSTRACT

In the first section of this paper, historical evidence concerning injuries occasioned by falling meteorites, including the recent Aba, Japan, incident described by I. Yamamoto and S. Murayama in the preceding notes is presented. In the second section, the possibility of injury from meteoritic falls is critically examined from the viewpoint of the theory of probability. It is found that the probability of a hit on the Human Target-Area (HTA) of Europe (or of America) during any century between 1600 A.D. and 2200 A.D. is very small. There are, however, about 316 chances out of 1000 that at least one meteorite will strike in the world's HTA during the 20th century. Furthermore, there is very nearly a 50-50 chance for at least one meteorite to hit in the same HTA during the 3 centuries from 1700 to 2000 A.D. Finally, the odds are 99 to 1 that in at least one of the centuries between 2100 and 3300 A.D. at least one meteorite will hit in the world's HTA.

**1.** *The Historical Evidence.*—The importance of the preceding notes by the Japanese meteoriticists, I. Yamamoto and S. Murayama, is obvious. The possibility of injury from falling meteorites is a subject of perennial interest, and, in view not only of the expanding target offered by the steadily and ever-more-rapidly increasing population of the Earth, but also of man's imminent abandonment of the protection normally afforded him by the atmosphere against all but the largest cosmic projectiles, the subject is certainly not one of merely academic interest. Nevertheless, up to the present time, it has not been possible to present, on the basis of the historical record, satisfactory proof that serious or fatal injuries to man or beast from meteoritic falls have occurred. As the following selected list (Table 1) will show, this difficulty arises not from any dearth of apparently relevant incidents but chiefly from the absence of *material* evidence that the missiles involved in the accidents were genuinely meteoritic and the impossibility of subjecting to critical questioning either survivors or eyewitnesses of the sensational events described.

TABLE 1

LIST OF INJURIES REPORTEDLY CAUSED BY FALLING METEORITES

| | |
|---|---|
| 1. *c.* 1500 B.C. | ". . . . . as they fled from before Israel, and were in the going down to Beth-horon, that the Lord cast down great stones from heaven upon them unto Azekah, and they died: . . ." (Book of Joshua 10:11)<br>No specimen was recovered and preserved. |
| 2. 616 Jan. 14 | ". . . . . a stone fell in China, shattering chariots and killing 10 men." (E. Biot)<br>No specimen was recovered and preserved. |
| 3. 1511 Sep. 14 | Birds and sheep and one Franciscan friar were killed during the fall of more than 1000 stones at Crema, near Milan, Italy. (T. F. Phipson)<br>No specimen was recovered and preserved. |

| | | |
|---|---|---|
| 4. | 1647-1654 | Sometime in this interval a mass weighing 4 kg. fell upon the bridge of a ship sailing at full speed between Japan and Sicily and killed 2 sailors. (Captain Olaus-Ericson Willmann)<br>No specimen was recovered and preserved. |
| 5. | 1794 June 16, 7:00 P.M. | One of the meteorites of the *recognized* howarditic-chondrite shower at Siena, Italy, pierced the hat of a child who was merely (badly) frightened. (S. Meunier) |
| 6. | 1825 Jan. 16 | A meteorite that fell at Oriang (Malwate) in British India killed a man and seriously injured a woman. (S. Meunier)<br>No specimen was recovered and preserved. |
| 7. | 1827 Feb. 16, 3:00 P.M. | A fragment of the *recognized* Mhow, India, meteorite ". . . wounded a man severely in the arm." (N. Story-Maskelyne) |
| 8. | 1836 Nov. 11, 5:00 A.M. | Stones from the *recognized* Macao, Brazil, meteoritic shower battered several cattle to death. (S. Meunier) |
| 9. | 1847 July 14, 3:45 A.M. | The 17-kg. mass of the *recognized* Braunau, Bohemia, meteorites fell into a bedroom where 3 children were sleeping and covered them with debris, but they were not seriously injured. (F. Heide) |
| 10. | 1860 May 1, 12:45 P.M. | A stone of the *recognized* New Concord, Ohio, shower killed a colt. (J. C. Steele) |
| 11. | 1870 Jan. 23, 7:00 P.M. | The *recognized* Nedagolla, India, meteorite struck so close to a man that he was stunned. (G. H. Saxton) |
| 12. | 1911 June 28, 9:00 A.M. | A meteorite of the *recognized* Nakhla, Egypt, shower killed a dog. (F. Heide) |
| 13. | 1927 Apr. 28, 9:00 A.M. | The *recognized* Aba, Japan, meteorite hit and injured a girl. (I. Yamamoto) |
| 14. | 1938 June 24, 6:05 P.M. | Immediately after the *recognized* Chicora, Pennsylvania, meteorites fell, a cow in a field neighboring the area where finds were made ". . . was discovered to have its hide torn downward as if struck a glancing blow by a falling stone . . ." (F. W. Preston) |

As regards human injury, the Aba, Japan, incident listed in Table 1, both because of its recency and because of Dr. Yamamoto's competence as a scientist, would seem to deserve the largest measure of credence. Nevertheless, certain points concerning the Aba stone have remained obscure; and it is particularly disturbing that as yet no careful analysis proving the meteoritic nature of the Aba specimen has been published. Consequently, as soon as favorable relations between the Institute of Meteoritics of the University of New Mexico and the Japanese meteoriticists were established thru the intermediation of Sgt. Victor E. Padilla, U.S.A.F., formerly a field assistant of the Institute, I began to urge that full details of the Aba fall be published and that the true nature of the recovered stone be determined. The results obtained to date are contained in the foregoing notes of I. Yamamoto and S. Murayama. No doubt the skepticism evinced in the latter's comment (Part II) is justified, but it should be pointed out that large masses

of enstatite from the recognized achondritic shower of 1948 February 18 in Norton County, Kansas, and Furnas County, Nebraska, show, like the Aba specimen, no magnetism, exhibit no nickel-iron grains, and have about the same density as Aba. Furthermore, Dr. Yamamoto's comment concerning the high velocity of the tiny stone is surely pertinent, for the Aba specimen seems much too small to have been chosen even by children as slingshot ammunition, but it is too large and too irregular to have been discharged from an air-rifle; and it is not easy to imagine other silent devices capable of giving such a high velocity to so tiny a mass.

Irrespective of the result of Murayama's critical study of the Aba stone (the outcome of which will be awaited impatiently by all meteoriticists), the probability question suggested by the mere existence of such a list of incidents as that in Table 1 seems of sufficient interest to merit theoretical consideration. In the next section, this problem of the probability of meteoritic hits on the Human Target-Area (HTA) is formulated and solved.

**2.** *The Theory of Meteoritic Hits on the HTA.*—From the viewpoint of infalling meteorites,[1] even those descending almost vertically, the human "targets of opportunity" beneath them must present widely varying attackable areas ranging from that of the minimum or "end-on" projection of the standing infant thru those characteristic of the innumerable attitudes in which human beings worship, work, and play, to the maximum projection of the recumbent adult. Since the typical human target may be idealized as a right circular cylinder of height $H$ and radius $R$, and since the involuntary and voluntary "librations" of this cylinder, just referred to, tend to equalize the opportunities for an infalling meteorite to attack its end-on and lateral projections, the effective target area presented by the cylinder to an infalling meteorite is approximated by the average, $\overline{A_1}$, of the area, $a_1$, of the end-on projection of this cylinder, and the area, $a_2$, of the *lateral* projection of the same cylinder. Thus,

$$\overline{A_1} = \frac{a_1 + a_2}{2} = \tfrac{1}{2}(\pi R^2 + 2RH). \tag{1}$$

By approaching this question from a less intuitive viewpoint, we can determine an upper bound for the effective target-area presented by the representative cylinder to infalling meteorites.[2] Consider a rectangular $XYZ$-coördinate system so chosen that the representative (rectilinear) meteoritic trajectory lies in the $XZ$-plane. Let this representative trajectory make an angle $\phi$ $(0 \leqq \phi \leqq \pi/2)$ with the $Z$-axis. Replace the target cylinder by an *equivalent target*, $T$, consisting of a circle of area, $a_1$, lying in the $XY$-plane with its center at the origin, $O$, of the $XYZ$-coördinate system, and a rectangle of area, $a_2$, lying in the $YZ$-plane, having a width equal to the diameter of $a_1$ and having its vertical sides bisected by the particular diameter of $a_1$ that lies along the $Y$-axis. The

segment of the $Z$-axis intercepted within the rectangle, $a_2$, will be referred to as the *axis* of the equivalent target, $T$. When $T$ is regarded as free to pivot about the origin, $O$, of the $XYZ$-coördinate system, let its orientation with respect to the $Z$-axis be determined by $i$, the smaller of the 2 supplemental angles between the axis of $T$ and the $Z$-axis. Thus, as in geometric optics, $0 \leqq i \leqq \pi/2$. Observe that all possible trajectory-target orientations are realizable by thinking of $T$ as fixed in a "standard position," *viz.*, that for which $i = 0$, and by then permitting $\phi$ to vary from 0 to $\pi/2$. In order to obtain an upper bound for the target-area attackable by vertically infalling meteorites, we shall assume that all values of $\phi$ in the range $0 \leqq \phi \leqq \pi/2$ are equally likely. Since it is natural to measure the target-area attackable by a meteorite moving in the direction $\phi$ by the function

$$a(\phi) = a_1 \cos \phi + a_2 \sin \phi,$$

it then follows that, under our hypotheses, the average effective target-area, $\overline{A_2}$, is given by the expression

$$(2) \qquad \overline{A_2} = \frac{2}{\pi} \int_0^{\pi/2} a(\phi)\, d\phi = \frac{2}{\pi} (a_1 + a_2) = \frac{2}{\pi} (\pi R^2 + 2RH).$$

From measurements of adults and children, we are led to adopt for the radius of the representative cylinder, $R = 0.5$ ft., and for the height of this cylinder, $H = 4.0$ ft. Whence, from (1), $\overline{A_1} = 2.393$ square ft., and from (2), $\overline{A_2} = 3.043$ square ft. The latter value is certainly somewhat too large, and, indeed, the former may be also; but, having regard for the fact that the falling meteorites are not points but are of finite (altho usually small) size, we shall adopt in the sequel 2.75 square ft. as the approximate value of the target-area presented by the average human being.

In order to estimate the size of the *group target* presented during any century by all the human beings living in various terrestrial areas, we shall need information concerning the changing populations of those areas. Such populational data are given in Table 2 for Europe, for the United States, and for the entire world. (The values inclosed in parentheses have been derived by extrapolation from populational formulas that closely fit actual census data over the intervals for which such data are available.)

The populational entries corresponding to the mid-centuries may be regarded as giving the *average population* of the area in question for each century included in the table. For dates earlier than 1600, no reliable data are available, but, for dates later than 2150, unless nuclear-biologic warfare intervenes, there are excellent reasons for expecting the population of the world as a whole and of its various subregions to remain nearly constant at the values attained in 2150.

The HTA entries are the group target-areas (in square miles) afforded by the average populations in question, computed by use of 2.75

square ft. as the target-area presented by the representative human being.

The probabilities listed in the column headed $P$ are obtained as follows: From the best data available to me it appears that approximately $N = 350{,}000$ individual meteorites actually reach the surface of our globe each century. Since these missiles fall at random, the probability that any one of them will strike a specified HTA is simply the value $p$, obtained by dividing the HTA by $2 \times 10^8$, the area of the Earth in square miles; hence, the probability that at least one of the $N$ meteorites falling per century will strike the specified HTA is given by $P = 1 - (1 - p)^N$; consequently, since $p$ is very small and $N$ is very large, $P$ is given very closely by the approximation

$$P = 1 - e^{-Np}, \tag{3}$$

from which the $P$-values given in Table 2 were computed (page 438).

Consideration of the $P$-values tabulated in Table 2 leads to a number of interesting conclusions. In the first place, the chance that during any particular one of the centuries comprized in Table 2, at least one meteorite will hit in the HTA's of Europe or the United States is *very* small, negligibly so in the latter case. As regards the entire world, there are about 316 chances out of 1000 that at least one meteorite will strike in its HTA during the 20th century. Altho this probability is not large (the professional gambler would certainly demand favorable odds before betting on the occurrence of such an event!), it is by no means as negligible as has been asserted by those writers that would have us rely on guesses rather than on calculation. To this extent, the theory of probability lends credence to the Aba incident.

On the basis of the data tabulated in Table 2, the *average* HTA for the entire world during the 3 centuries from 1700 to 2000 approximates 139 square miles. If the value of $P$ corresponding to this HTA is computed, it is found that there is very nearly a 50-50 chance for at least one meteorite to hit this HTA during the 3 centuries in question. Until further details on the Aba stone become available, both Chyu Kuriyama and the unnamed individual involved in the Mhow incident sponsored by the famous critic, N. Story-Maskelyne, remain moderately promising candidates for the questionable honor of having been the one of all the billions inhabiting the Earth during these 3 centuries whose number was on a falling meteorite!

There is another way of looking at the question of meteoritic hits on HTA's that may appeal to those that like to bet on a "sure thing." As previously noted, there are cogent reasons for expecting the world's HTA to remain nearly constant from about 2100 A.D. onward. Since $N$ may be regarded as constant, it follows that the probability, $P$, should remain substantially constant at about 0.4 from century to century after 2100 A.D. Accordingly, the probability, $P^*$, that in at least one of the

TABLE 2

POPULATIONAL DATA FOR EUROPE, THE UNITED STATES, AND THE WORLD

| Year | *EUROPE* | | | *UNITED STATES* | | | *WORLD* | | |
|---|---|---|---|---|---|---|---|---|---|
| | Population in millions | HTA in sq. mi. | *P* | Population in millions | HTA in sq. mi. | *P* | Population in millions | HTA in sq. mi. | *P* |
| 1500 | 100 | | | .... | | | 400 | | |
| 1550 | 100 | 9.863 | 0.017 | .... | ..... | ..... | 426 | 42.02 | 0.072 |
| 1600 | 100 | | | (0.05) | | | (452) | | |
| 1650 | 110 | 10.85 | 0.018 | (0.14) | 0.0138 | 0.000 | (544) | 53.65 | 0.090 |
| 1700 | 120 | | | (0.23) | | | (637) | | |
| 1750 | 153 | 15.10 | 0.026 | 2.2 | 0.2170 | 0.000 | 771 | 76.05 | 0.125 |
| 1800 | 187 | | | 5.3 | | | 906 | | |
| 1850 | 294 | 28.99 | 0.050 | 41. | 4.043 | 0.007 | 1257 | 124. | 0.196 |
| 1900 | 401 | | | 76. | | | 1608 | | |
| 1950 | 549 | 54.16 | 0.091 | 131. | 12.92 | 0.023 | 2197 | 216.7 | 0.316 |
| 2000 | (697) | | | (186.) | | | (2787) | | |
| 2050 | (720) | 71.01 | 0.117 | (192.) | 18.93 | 0.033 | (2881) | 284.2 | 0.392 |
| 2100 | (744) | | | (198.) | | | (2975) | | |
| 2150 | (750) | 73.98 | 0.122 | (200.) | 19.72 | 0.035 | (3000) | 295.9 | 0.405 |

$\nu$ centuries after 2100 at least one meteorite will hit in the HTA of the world, is given by

$$P^* = 1 - e^{-\nu P} = 1 - e^{-0.4\nu}. \tag{4}$$

If we assign to $P^*$ the value 0.99 and seek to determine the corresponding value of $\nu$, we find $\nu = 11.5$; hence, it is almost certain that in at least one of the centuries between 2100 A.D. and 3300 A.D., at least one meteorite will strike the HTA in question. Inhabitants of the formidable world of Day-after-Tomorrow may regard this meteoritic danger as the *least* of the hazards to which they are subject, however!

NOTES

[1] Either natural or such artificial meteorites as will result from the debris of rockets, satellite vehicles, and space-ships that come to grief during experimentation or are shot down during battles fought at extreme altitudes.

[2] The considerations developed hereinafter are immediately applicable to the problems of meteoritic hits on a Building Target-Area (BTA) or on a Space-ship Target-Area (STA). The results obtained by such applications will be published in a later paper.

## Report on the 14th Meeting of the Society

JOHN A. RUSSELL, *Secretary*
Department of Astronomy, University of Southern California, Los Angeles 7, California

The 14th Meeting of the Meteoritical Society was held 1951 June 18-19, on the campus of the University of Southern California in Los Angeles, in conjunction with the annual meeting of the Pacific Division of the American Association for the Advancement of Science.

The opening session for papers on Monday afternoon, June 18, was attended by the following 9 members and a considerably larger number of guests: A. R. Allen (Trinidad, Colorado), J. D. Buddhue (Pasadena, California), A. S. King (Pasadena, California), F. C. Leonard (Los Angeles, California), O. E. Monnig (Fort Worth, Texas), A. P. Ousdal (Santa Barbara, California), J. A. Russell (Los Angeles, California), W. J. C. Weiss (San Antonio, Texas), and P. E. Wylie (Los Angeles, California).

In the absence of both the President and a Vice-President, the meeting was opened by the Secretary, who, after a few preliminary announcements, requested Editor Leonard to preside. Sixteen (16) papers were presented, those marked (*) by proxy and those marked (†) by title only.

### LIST OF PAPERS READ AT THE 14TH MEETING
(in the order of presentation)

*Afternoon Session, June 18*

1. "An Apparent Effect of Wind on the Spectra of Meteors," John A. Russell, University of Southern California, Los Angeles, California.
2. "Constructional Names and Symbols for the Subclasses in the

Simplified Classification of Meteorites," Frederick C. Leonard, University of California, Los Angeles.

3. "The Total Known Weight of the Cape York, Greenland, Siderite Fall (ECN = + 0650,760:)," Frederick C. Leonard.

4. "The Volcanic Craters of the Pinacate Region of Northern Sonora, Mexico," Richard H. Jahns, California Institute of Technology, & William C. Miller, Mount Wilson & Palomar Observatories, Pasadena, California (introduced by F. C. Leonard; paper presented by Mr. Miller).

5. "The Determination of the Coördinates of a Meteor by Orthographic Projection," Paul E. Wylie, University of California, Los Angeles.

6. "A Preliminary Report on the Naruna, Burnet County, Texas, Meteorites," Oscar E. Monnig, 1010 Morningside Drive, Fort Worth, Texas.

7. "The Brunton Transit in Fireball Surveys," Oscar E. Monnig.

*8. "The Determination of the Geologic Age of Two Stony Meteorites by the Argon Method," E. K. Gerling & T. G. Pavlova, translated from the Russian by Walter Nichiporuk, University of Chicago, Chicago, Illinois (introduced by H. Brown; paper read by Dr. Leonard).

*9. "A Report on the Fall of the Monze, Northern Rhodesia, Meteorite, 1950 October 5," H. H. J. Lambert, Government Geophysicist, Monze, Northern Rhodesia (introduced by J. A. Russell, and paper read by him).

†10. "The Classifications and Total Known Weights of 568 Meteoritic Falls," Frederick C. Leonard & Gerald L. Rowland, University of California, Los Angeles.

*Morning Session, June 19*

*11. "A Very Bright Fireball with an Enduring and Drifting Train," Mohd. A. R. Khan, Begumpet, Deccan, India (read by Dr. Leonard).

12. "Microscopic Flora and Fauna Present in Meteoritic Mineral Deposits," Asbjorn P. Ousdal, P. O. Box 807, Santa Barbara, California.

13. "The Shapes of Craters Produced in Plaster-of-Paris Targets by Ultra-speed Pellets," John S. Rinehart & W. C. White, U. S. Naval Ordnance Test Station, Inyokern, China Lake, California (read by Mr. White).

*†14. "The Gladstone, New Mexico, Meteorite," Carl W. Beck, Lincoln LaPaz, & Robert Heneks, University of New Mexico, Albuquerque.

*†15. "Applications of Autoradiographic, Tracer, and Other Modern Nuclear Techniques in Meteoritics," Lincoln LaPaz, University of New Mexico, Albuquerque.

*†16. "The Aba, Japan, Aerolite: A Recent Meteoritic Fall that Injured a Human Being," Issei Yamamoto, Kwasan Observatory, Kyoto

University, Kyoto, & Sadao Murayama, The Tokyo Science Museum, Tokyo, Japan (introduced by L. LaPaz).

At the close of the Monday afternoon session, the Society dinner was held in the University Commons.

Monday evening, the Meteoritical Society and the Astronomical Society of the Pacific were the guests of Director Dinsmore Alter, of the Griffith Observatory and Planetarium in Griffith Park, at a special planetarium presentation of "A Trip to the Moon."

A small but fairly representative collection of meteorites, including a piece of the recently fallen Monze, Northern Rhodesia, aerolite (described in paper no. 9, *ante*), was on display thruout the meeting, in one of the U.S.C. buildings.

On Wednesday, June 20th, activities were transferred to the campus of the California Institute of Technology in Pasadena, where the members of the Society were the guests of the Institute and of the Astronomical Society of the Pacific at a morning symposium on "Radial-Velocity Programs of Pacific-Coast Observatories." The program at the Institute, after the symposium, included visits to the new synchrotron, a display of photographs taken with the Palomar telescopes, a 1/10-scale model of the 200-inch Hale telescope, and an exhibit of astronomical photometers and measuring engines.

A trip to the Mount Wilson Observatory on Wednesday afternoon provided a fitting climax to the 14th Meeting, which, altho not one of the largest meetings of the Society in point of attendance, was, nevertheless, a very successful one, especially as regards the quality, quantity, and variety of the papers presented.

*President of the Society:* L. F. BRADY, 922½ Forest Avenue, Tempe, Arizona
*Secretary of the Society:* JOHN A. RUSSELL, Department of Astronomy, University of Southern California, Los Angeles 7, California

## The Planets in November, 1951

By RAYMOND H. WILSON, JR.

NOTE: The time employed is Central Standard Time unless otherwise indicated. The phenomena have been chosen and described for the North American continent, and especially for the United States. The basic data have been taken principally from the *American Ephemeris and Nautical Almanac*.

*Sun.* The sun will continue its usual autumn retreat to more southerly declinations. By the end of the month, it will be less than 2 degrees above its winter minimum of 23½ degrees south of the equator.

*Moon.* The phases of the moon will occur as follows:

| | | | |
|---|---|---|---|
| First Quarter | November | 6 | 1 A.M. |
| Full Moon | | 13 | 10 A.M. |
| Last Quarter | | 21 | 2 P.M. |
| New Moon | | 28 | 7 P.M. |

The moon will be at its nearest to the earth on November 2 and 30.

An occultation of $\rho$ Leonis, the brightest star immediately southeast of Regulus, will be visible from the southern third of the United States on November 22 at about 1:30 A.M.

*Evening and Morning Stars.* Jupiter will dominate the evening sky, while Mars, Venus, and Saturn will be rising as a group, in that order, at about three in the morning.

*Mercury.* Mercury will be at a greatest elongation of 22 degrees east of the sun on November 28, but its extreme southern declination at that time will be unfavorable to visibility from northern latitudes.

*Venus.* This, the most brilliant planet, will be rising in the east shortly after Jupiter has set in the west. Since it will stand at a greatest western elongation of nearly 47 degrees on November 14, Venus will be most favorably situated for observation in the morning sky during this month.

*Mars.* Mars will appear as a second magnitude star, slightly fainter than Regulus, within 10 degrees to the northwest of Venus in the morning sky.

*Jupiter.* Its coming to perihelion this month will combine with the opposition on October 3 to make observation of Jupiter in the evening at this time the most favorable for a decade.

*Saturn.* On November 21 at 4 A.M. Venus will pass only half a degree to the south of Saturn. This conjunction should be a notable planetary sight in the morning sky of that date.

*Uranus.* Uranus will be slowly retrograding northwestward at a point two-thirds of the distance from $\xi$ to $\omega$ Geminorum.

*Neptune.* Neptune will be moving east-southeastward at about 4 degrees north of Spica. On the morning of November 29, Venus will pass it only half a degree to the north.

Department of Mathematics, University of Louisville, Kentucky.
September 1, 1951.

## Occultation Predictions for November, 1951

(Taken from the *American Ephemeris*)

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b;* apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

| Date 1951 | Star | Mag. | IMMERSION Greenwich C.T. | a | b | Angle E from N | EMERSION Greenwich C.T. | a | b | Angle E from N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | h m | m | m | ° | h m | m | m | ° |
| **Occultations Visible in Longitude +72° 30′, Latitude +42° 30′** | | | | | | | | | | |
| Nov. 5 | 17 Capr | 5.9 | 20 52.8 | −1.6 | +1.2 | 58 | 22 11.0 | −1.8 | +0.5 | 251 |
| 6 | γ Capr | 3.8 | 20 2.5 | −1.2 | +0.9 | 111 | 20 51.8 | −1.0 | +2.2 | 197 |
| 16 | 107 B.Auri | 6.5 | 10 4.1 | −0.8 | −2.2 | 117 | 11 12.1 | −0.8 | −1.1 | 259 |
| 22 | 49 Leon | 5.8 | 16 10.9 | −2.9 | +1.6 | 76 | 11 2.5 | 0.0 | −3.5 | 1 |
| 26 | 85 Virg | 6.2 | 10 47.7 | −0.7 | +0.3 | 119 | 11 54.2 | −0.9 | −0.1 | 310 |
| **Occultations Visible in Longitude +91° 0′, Latitude +40° 0′** | | | | | | | | | | |
| Nov. 16 | 107 B.Auri | 6.5 | 9 56.4 | .. | .. | 153 | 10 43.0 | .. | .. | 220 |
| 22 | 49 Leon | 5.8 | 9 33.0 | −1.3 | +0.3 | 112 | 10 51.4 | −1.4 | −1.2 | 318 |
| 24 | 46 B.Virg | 6.5 | 9 51.9 | −1.3 | +2.9 | 69 | 10 29.4 | +0.2 | −3.0 | 2 |
| 25 | ψ Virg | 4.9 | 10 16.8 | −0.6 | +0.9 | 101 | 11 15.7 | −0.4 | −0.7 | 328 |
| **Occultations Visible in Longitude +98° 0′, Latitude +31° 0′** | | | | | | | | | | |
| Nov. 9 | 14 Pisc | 6.0 | 6 15.6 | −0.1 | +2.8 | 4 | 6 59.0 | −1.3 | −2.1 | 285 |
| 19 | 35 B.Canc | 6.4 | 8 42.3 | .. | .. | 38 | 9 13.0 | .. | .. | 1 |
| 22 | ρ Leon | 3.8 | 7 44.5 | −0.3 | +2.3 | 70 | 8 32.3 | −0.7 | −2.2 | 342 |
| 22 | 49 Leon | 5.8 | 9 30.3 | −1.0 | −1.6 | 150 | 10 42.8 | −2.2 | +0.5 | 278 |
| 24 | 46 B.Virg | 6.5 | 9 35.4 | −0.5 | +0.2 | 114 | 10 40.3 | −0.7 | −0.7 | 315 |
| **Occultations Visible in Longitude +120° 0′, Latitude +36° 0′** | | | | | | | | | | |
| Nov. 22 | 49 Leon | 5.8 | 9 9.7 | −0.4 | −0.3 | 135 | 10 14.0 | −0.9 | +0.9 | 279 |

## Meteor Notes from the American Meteor Society

**By CHARLES P. OLIVIER, President**

Before presenting the fireball solution which forms the regular contribution in these "Notes," both on behalf of the American Meteor Society and even more for myself, I wish to express our deepest regret at the sudden death of Dr. Curvin H. Gingrich whose constant interest in our Society and careful editing of our results have so greatly increased the value of what we have done. About 24 years ago, we had some correspondence about placing more regular articles on the current work of our Society in *Popular Astronomy*, though indeed our annual reports and occasional articles had appeared there already for over a dozen years. With his encouragement and approbation, these "Meteor Notes" were started and have appeared in the majority of issues of *Popular Astronomy* ever since. It is needless to point out to our members what an immense aid and inspiration it has been to have at least some of our results appear many times per year, instead of only at very long intervals. Personally, Dr. Gingrich and I had known each other for several decades and he was one of my best friends in Astronomy. His death was a loss to me that will not be filled. Others have already written at length concerning his life, work, and character, but I should like to sum up the latter by saying that he was a Christian gentleman of the highest type and I know of no higher praise.

### The Missouri-Illinois Fireball of 1950 October 4

*By* Edwin E. Friton and C. P. Olivier

On this date at about 5:20 P.M., C.S.T., while still full daylight, a fine fireball appeared over central Missouri and going somewhat south of east ended over Illinois. E. E. Friton, who is regional director for this section, at once took the

various steps necessary to secure as many reports as possible. In this he was eminently successful, and a total of 145 persons, not counting newspaper reports which as usual are almost wholly lacking in value, sent in information. In a number of cases, Friton personally visited the locality carrying a surveyor's transit and compass with him, as soon as was practicable after the event. The persons then pointed out to him where the object started and stopped, as they saw it, and he made instrumental measurements of the altitudes and azimuths. In other cases, our *Bulletin No. 16* was sent to and filled out by the observer. Besides all this, many letters asking for specific information on certain points had to be written, and the total time consumed in gathering and sorting the data was very large. Eventually, when Friton had abstracted these various reports, they were sent to Flower Observatory for final computation. There three others, which had come directly, were added. An opportunity to work on these data came during recent weeks, and the actual computation of the atmospheric path and orbit has just been completed by Olivier in time for these "Notes." But without the great expenditure of time and trouble by Friton, and his ability in arousing interest in his and neighboring states, we would have no useful information about this fine fireball, only the mere fact it appeared on the date and at the time reported in the papers.

Despite the large amount of data, the case presented certain difficulties in solution. First, being daytime, there were no stars or other celestial objects which could be used for reference points. Second, few observers even claim to have seen the beginning point itself. Third, we did not have the luck to get an observation from anyone who saw it go through his zenith, or indeed who saw it have a definite perpendicular path. Fourth, the main object ended, it seems, in an outburst of light or sort of explosion, after which fragments went further, probably even in a path of somewhat different inclination. This has complicated the determination of the sub-end point. And, lastly, we have the fewest observations from east of the end point and none which says the object ended overhead. What looks like an authentic report from Waterloo, Illinois, about fragments falling in a plowed field (but which could not be found) seems unlikely, as the point is considerably south of any path that could be deduced for the fireball. Further remarks about this report are hence omitted, because, even assuming meteorites fell, they could hardly have been from this fireball.

For the projected path, the usual procedure of preparing a map on proper projection and covering the needed region was carried out. Then the latitudes and longitudes of the stations from which useful observations had been made were measured off from a standard atlas and then plotted on our map. Incidentally, I found it much better and more expeditious to measure the coördinates in hundredths of a degree rather than in minutes of arc. The actual scale was 50 mm = 1° of latitude, of 1 mm = 2.214 km. Next, the projected end point was determined, and then a point further on, which seemed that above which the fragments disappeared. In this selection, I admit using my own judgment rather than any fixed rule but believe that the methods employed brought about a fairly good result. The sub-beginning point was far harder to determine. For this, I selected the center of gravity of all the azimuth projections which seemed usable for the purpose. Other considerations make me believe that, even if the point is not too well determined, yet the azimuth of the path, on which along with the slope the radiant depends, is about correct. To determine the heights of beginning and end point, the usual method was used for the latter, but for the former a series of approximations, depending upon the average estimated slope as seen from St. Louis and

nearby stations and upon the heights of points observed along the path, were the main reliance. This is because the 4 observers who thought they saw the beginning point all said 45° altitude, and it is notorious that 45° thus stated most often is really about 30°. Hence the beginning height was calculated using 45° + correction for curvature, then using 30° without correction, and the end point falls, as expected, between these extreme values and nearer the second. However, despite these troubles and possible errors, it is probably that the azimuth of the radiant is correct within 2° or 3°, and the altitude within about the same limits. For a daylight object such errors are not large. The derived data now follow:

| | |
|---|---|
| Date | 1950 Oct. 4.47 G.M.T.; Oct. 4.97 G.C.T. |
| Sidereal time at end point | 273° |
| Began over | λ 91° 22′, φ 39° 27′; height 86 km |
| Ended over | λ 89° 03′, φ 38° 48′; height 28 ± 10 km |
| Last fragments over | λ 88° 42′, φ 38° 43′; height 22 ± 4 km |
| Length of path | 218 km |
| Projected length of path | 210 km |
| Duration | 3.57 ± 1.67 sec (?) |
| Velocity | 61 km/sec ?? |
| Radiant (uncorrected) | Azimuth 109°, Altitude 15° |
| Radiant (corrected) | Azimuth 109°, Altitude 13° 8′ |
| | R.A. 181°.8, Decl. + 22°.9 |
| | Long. 172°.1, Lat. 21°.6 |

This radiant is A.M.S. No. 2323.

The elements of the parabolic orbit follow:

$$i = 41°$$
$$\pi = 257°$$
$$\Omega = 191°$$
$$q = 0.30 \text{ A.U.}$$

With regard to the color, never have we found such unanimity of opinion: nearly every one said that the fireball was blue or bluish-white, with a short white tail. The latter seems to have disappeared at once; no long-enduring train was left. As to the duration again, there is remarkable unanimity in stating that it was very short, the actual number being 3.57 seconds based upon 14 estimates made by people who saw the whole path presumably. Nine more who state they saw but part give 2.0 seconds. If the former estimate is correct, the geocentric velocity would come out 61 km/sec which is considered excessively high. Indeed, we can have little confidence in the duration given above, but the strange thing is that only two out of 23 persons gave over 5 seconds, and we would expect a far greater spread in the estimates if the duration was really much longer. Is it possible that here we really have a hyperbolic orbit? As usual we have assumed parabolic heliocentric velocity in computing the zenith correction, and indeed the orbital elements just given. We have reports from 4 persons in 3 stations of definite noise such as we might expect from a large fireball or bolide. Two were at Greenville, Illinois, one each at St. Jacobs, Illinois, and Hillsboro, Illinois; all stations not too far from the end of the path. Incidentally, we have taken the length of path to be to where the main body disintegrated, not to the second point where the last fragments disappeared. Greenville was right under the path, but neither observer saw the fireball, only heard the noise later; the other two places are one south, the other north, of the path and about equally far, and almost in line with Greenville. Five other observers in assorted places report hissing, swishing, etc. But we find that the ages of four are 11, 15, 13, and 13 respectively: only the fifth is a grown person. While not denying the possibility that such phenomena

exist, in this case we consider the evidence so meager that we need discuss it no further. Finally, if any fragments did fall, they are to be sought in the counties of Fayette, Marion, and Clay in Illinois, though we think west of the town of Louisville in the last named county. However, the lack of any smoke train and the fact that the end height was probably 28 km for the main body both make the fall of meteorites at best improbable.

In closing, we wish to express our earnest thanks to the scores of persons who so kindly reported what they saw and, in so many instances, took additional time to answer more questions by letter or meeting E. E. Friton to point out the path as they saw it. It is obviously impossible to print a list of their names and addresses, or to give details of their actual individual observations, due to lack of space. But the two authors, both on their own behalf and even more on behalf of the American Meteor Society, wish to express our sincere appreciation to everyone who aided us. Without this generous aid, such solutions could not even be attempted. We further beg of these persons and all other readers always to report at once if they see a bright fireball, without waiting to be appealed to. In this way meteoric astronomy can be greatly advanced.

There is a report in the September *Sky and Telescope,* page 272, of a fall of meteorites about 4 A.M. on 1950 October 5 in Rhodesia, South Africa. As this time is 2 hours earlier than Greenwich, judging by the East Longitude given for the fall, and C.S.T. is 6 hours later, the total difference is 8 hours. Hence the fall occurred at about 8 P.M., C.S.T., on October 4. This is less than 3 hours after the appearance of the fireball we are discussing. It would hence be of the greatest interest if an orbit could be computed for these meteorites. In this case, a possible connection between the two bodies might be shown.

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Turning to the late Perseid maximum, reports are coming in and it is hoped that a résumé of what was accomplished can be placed in "Meteor Notes" this fall. Bad weather over much of the Eastern states ruined observations for a large part of our members, but fortunately others were favored by good skies. It is too early, as yet, to make any intelligent estimate as to whether the late return was average in richness or not. Our members are urged to work on the Orionids of October, the Leonids of November, and especially on the Geminids of December, the latter being, next to the Perseids, our best annual shower.

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In "Meteor Notes" for April, 1951, page 219, two typographical errors occur in the table of data on the fireball of 1948 October 14. First, the Length of Path and the Projected Length of Path are obviously reversed. Second, the declination of the radiant should be —11°, as indeed can be seen from the altitude given.

Flower Observatory of the University of Pennsylvania, Upper Darby, Pa.
1951 August 28.

# VARIABLE STARS

## Variable Star Notes from the American Association of Variable Star Observers

By MARGARET W. MAYALL, Recorder

224552 *DK Lacertae* (*Nova, 1950*). A very interesting discussion of the visual light curve of DK Lacertae was made by Záviš Bochníček, of the Astronomical Institute of Charles University, Prague. He used 356 visual observations made by 14 members of the Czechoslovak Astronomical Society. Dr. Bochníček found a light curve very similar to the one determined from AAVSO observations (see *P. A.*, **59**, 4, *222*, April, 1951), and with the same frequent outbursts. He noted 17 of these outbursts in the 600 days following maximum. The general over-all shape of the light curve is approximately logarithmic, and Dr. Bochníček found that the time interval between outbursts also could be expressed logarithmically, using the expression:

$$\log (t_n - t_o) = a + bn$$

where $t_n$ is the time of maximum of $n$ oscillation, and $t_o$, $a$, and $b$ are constants.

Charles Fehrenback and Andre Duflot, of the Observatoire de Haute-Provence, have published a photographic light curve of the nova for the first 200 days after maximum. The photographic observations show the same outbursts given in the visual curve.

The latest AAVSO observations show that the nova now has slight variations between the 12th and 13th magnitudes.

213843 *SS Cygni*. SS Cygni had another maximum the latter part of August, beginning J.D. 2,433,880, about 68 days after the last previous one. It is a narrow type maximum, but is well observed, for Holloway, Darling, Fernald, Rosebrugh, and Adams caught it on the way up. Maximum observations have been received from Darling, Fernald, Adams, Rosebrugh, Miller, Bogard, Holloway, and Galbraith; Herring, Rosebrugh, and Galbraith have observed it on the decrease near minimum.

2035*01 AE Aquarii*. AE Aquarii continues to be one of the most interesting and probably one of the most difficult objects to observe. When it starts to flare up, it changes so rapidly that several observers have remarked that they questioned the identification of the field. The observations of this season confirm the suspected nightly variation, for in several cases maxima have occurred two nights in succession. The times of observed maxima during July and August are as follows:

| J.D.243 | Mag. | Obs. | J.D.243 | Mag. | Obs. | J.D.243 | Mag. | Obs. |
|---|---|---|---|---|---|---|---|---|
| 3836.61 | 10.8 | Fe | 3863.60 | 10.9 | Fe | 3882.71 | 11.3 | SO |
| .64 | 11.2 | Fe | .61 | 11.3 | P | .71 | 11.3 | SO |
| 3851.61 | 11.1 | Fe | .71 | 11.5 | GB | .71 | 11.3 | SO |
| 3852.59 | 11.1 | Fe | 3864.71 | 11.1 | GB | .72 | 11.3 | SO |
| .61 | 11.2 | P | .72 | 11.0 | GB | .72 | 11.3 | SO |
| .62 | 11.3 | Fe | .75 | 10.7 | GB | .73 | 11.3 | SO |
| .67 | 10.8 | P | .75 | 11.1 | GB | .74 | 11.2 | SO |
| .68 | 11.0 | P | .76 | 11.3 | GB | .74 | 11.1 | SO |
| 3857.61 | 11.2 | P | .76 | 11.5 | GB | .75 | 11.0 | SO |
| .68 | 10.9 | P | .77 | 11.5 | GB | .76 | 10.9 | SO |
| .69 | 10.8 | P | 3865.58 | 11.1 | Fe | .76 | 10.9 | SO |
| .70 | 11.0 | P | .63 | 11.1 | Fe | .77 | 10.9 | SO |
| .71 | 11.2 | P | .70 | 11.4 | GB | .77 | 10.9 | SO |
| 3860.63 | 11.2 | P | 3881.58 | 10.7 | Fe | 3884.55 | 11.2 | Fe |
| .65 | 10.8 | Fe | | | | .59 | 11.0 | Fe |

Sometime during the observing season of 1952, we plan to have a special drive for observation of AE Aquarii. We will ask observers all over the world to devote a certain percentage of their observing time to a close watch of the star. In this way, we should be able to secure a complete story of the variable's actions.

142539 *V Boötis.* V Boötis has been going through some unusual changes in the shape of its light curve during the last year. In August, 1950, it had a still-stand at about 8.5 magnitude thirty days after maximum. Minimum occurred at the predicted time, at about 9.5 magnitude. Maximum occurred as predicted in April, 1951. About seventy days after maximum it had decreased smoothly to a little below 9.5 magnitude; it then started to rise, and in the latter part of July it was again about 9th magnitude. It decreased again in August, and the few observations received from the last of the month (near predicted minimum) give a mean of about 9.3 or 9.4. The mean M-m of V Boötis is 126 days.

*A Nova in the Small Magellanic Cloud.* An 11th magnitude nova was discovered August 4, 1951, in the Small Magellanic Cloud, by Mr. Karl G. Henize of the University of Michigan station in Bloemfontein, South Africa. It is the third nova to be found in the Small Cloud, and is of about the same maximum magnitude as the other two.

*Observations received during July and August, 1951.* In July, 3,190 observations were contributed, and in August, 5,280, making a grand total of 8,470 received from 79 observers during the two months.

| | July—1951—August | | | |
|---|---|---|---|---|
| Observer | No. Var. | No. Ests. | No. Var. | No. Ests. |
| Adams, R. M. | 47 | 122 | 53 | 116 |
| Ahnert, Paul | 24 | 106 | 22 | 204 |
| Ancarani, Mario | 28 | 66 | 26 | 52 |
| Behrens, Robert | .. | .. | 4 | 4 |
| Bicknell, R. H. | 18 | 200 | 20 | 302 |
| Blunck, V. H. | 8 | 11 | 12 | 14 |
| Bogard, David | 42 | 42 | 31 | 31 |
| Boone, Abram | 7 | 7 | 25 | 28 |
| Boutell, H. G. | 6 | 31 | 7 | 61 |
| Buckstaff, R. N. | 30 | 64 | 20 | 48 |
| Cain, C. V. | 3 | 3 | 2 | 2 |
| Chandra, R. G. | 35 | 48 | .. | .. |
| Charles, D. F. | 13 | 16 | 16 | 20 |
| Costello, R. B. | 8 | 8 | .. | .. |
| Cragg, T. A. | 60 | 61 | .. | .. |
| Dafter, Rosina | .. | .. | 9 | 65 |
| Darling, Birt | .. | .. | 19 | 56 |
| Darnell, P. B. | .. | .. | 1 | 5 |
| Darsenius, Gunnar | 8 | 10 | 21 | 41 |
| Diedrich, DeLorne | 3 | 4 | 1 | 1 |
| Diedrich, George | 3 | 9 | 6 | 17 |
| Domke, Klaus | .. | .. | 31 | 125 |
| Estremadoyro, G. A. | .. | .. | 5 | 8 |
| Estremadoyro, V. A. | 7 | 7 | .. | .. |
| Fernald, Cyrus | 108 | 131 | 184 | 363 |
| Fernald, Emily | 9 | 9 | 3 | 4 |
| Ficonetti, Rene | .. | .. | 33 | 41 |
| Ford, C. B. | .. | .. | 74 | 77 |
| Galbraith, W. H. | 38 | 112 | 58 | 200 |
| Goodsell, J. G. | 5 | 5 | .. | .. |

| | July—1951—August | | | |
|---|---|---|---|---|
| Observer | No. Var. | No. Ests. | No. Var. | No. Ests. |
| Greenley, R. M. | 71 | 157 | 76 | 135 |
| Halvorson, D. O. | .. | .. | 11 | 20 |
| Hamilton, R. W. | .. | .. | 4 | 4 |
| Hartmann, Ferdinand | 120 | 121 | 121 | 127 |
| Hiett, Lancaster | 24 | 47 | .. | .. |
| Holloway, Leith | .. | .. | 8 | 9 |
| Huffer, R. C. | .. | .. | 7 | 11 |
| Jerabek, H. S. | 8 | 21 | 11 | 28 |
| Kanda, Sigeru | .. | .. | 10 | 188 |
| Kelly, F. J. | 13 | 13 | 10 | 14 |
| Kirchhoff, Peter | 33 | 79 | 31 | 53 |
| Knowles, Jeremy | 6 | 6 | 10 | 73 |
| de Kock, R. P. | 125 | 642 | 133 | 444 |
| Leutenegger, Emil | .. | .. | 17 | 17 |
| LeVaux, Howard | 28 | 28 | .. | .. |
| Luft, H. A. | 5 | 9 | 6 | 39 |
| Meek, J. W. | .. | .. | 38 | 229 |
| Melville, E. C. | 7 | 9 | 8 | 13 |
| Miller, W. A. | 35 | 84 | 47 | 93 |
| Milone, L. A. | 12 | 12 | 32 | 56 |
| Montague, A. C. | 34 | 56 | 40 | 52 |
| Morrisby, A. G. F. | 12 | 30 | 34 | 130 |
| Motley, Gary | 28 | 71 | 38 | 85 |
| Oravec, E. G. | 54 | 123 | 48 | 164 |
| O'Sullivan, W. H. | 6 | 7 | 11 | 21 |
| Parker, P. O. | .. | .. | 40 | 40 |
| Patterson, K. E. | .. | .. | 7 | 10 |
| Pearcy, R. E. | 7 | 7 | 10 | 10 |

| Observer | July—1951—August No. Var. | No. Ests. | No. Var. | No. Ests. |
|---|---|---|---|---|
| Peltier, L. C. | 44 | 156 | 54 | 194 |
| Peter, Hermann | .. | .. | 28 | 155 |
| Reeves, W. P. | .. | .. | 1 | 2 |
| Renner, C. J. | 100 | 100 | 201 | 378 |
| Richter, Gerold | .. | .. | 10 | 54 |
| Rick, Louis | .. | .. | 2 | 2 |
| Rosebrugh, D. W. | 19 | 99 | 21 | 149 |
| Schulte, Dan | 10 | 15 | .. | .. |
| Segers, C. L. | 7 | 38 | 15 | 38 |
| Shan, Theodore | .. | .. | 3 | 3 |
| Snow, Dan E. | .. | .. | 7 | 19 |
| Sofronijewitsch, D. | .. | .. | 24 | 194 |
| Taboada, Domingo | 36 | 36 | 13 | 13 |
| Tarwater, Charles | 35 | 43 | .. | .. |
| Tifft, W. G. | .. | .. | 17 | 20 |
| Upjohn, L. N. | .. | .. | 52 | 52 |
| Venter, S. C. | 32 | 46 | .. | .. |
| Weber, J. A. | 19 | 19 | 20 | 20 |
| Welker, Frank | 23 | 25 | 29 | 37 |
| Wells, K. A. | 9 | 9 | .. | .. |
| Whitehill, S. L. | 7 | 10 | .. | .. |
| | 79 | 3,190 | | 5,280 |

*Nova Search.* Nova Search reports were received during July and August from 10 observers, as follows:

| | JULY | | | AUGUST | | |
|---|---|---|---|---|---|---|
| | Area | No. Nights | Mag. | Area | No. Nights | Mag. |
| Adams, R. M. | 39, 40, 57, 58 | 3 | 8 | 39, 40 | 4 | 8 |
| | 172, 173 | | | | | |
| | | | | 57, 58 | 5 | 8 |
| | 172, 173 | 1 | 7 | | | |
| | | | | 86, 87 | 2 | 8 |
| | | | | 172, 173 | 3 | 8 |
| Blunck, V. H. | 8, 9, 10 | 3 | 6 | 8, 9, 10 | 3 | 6 |
| Darsenius, Gunnar | ... | .. | .. | 16 | 2 | 5 |
| | | | | 16 | 5 | 4 |
| *Diedrich, DeLorne | 40 | 1 | 6 | 40 | 1 | 5 |
| *Diedrich, George | Dome | 2 | 2 | Dome | 1 | 2 |
| | 78 | 1 | 6 | Dome | 1 | 1 |
| | 78 | 1 | 5 | 78 | 1 | 6 |
| | | | | 78 | 3 | 5 |
| | | | | 78 | 1 | 4 |
| Luft, H. A. | 28, 30, 90 | 3 | 5 | 28, 29, 30 | 9 | 5 |
| *Rick, Louis | Dome | 8 | 1 | Dome | 10 | 1 |
| | 18, 63 | 1 | 6 | 18 | 8 | 4 |
| | 18 | 1 | 4 | 63 | 5 | 5 |
| | 18 | 3 | 3 | 63 | 5 | 4 |
| | 63 | 1 | 5 | | | |
| | 63 | 4 | 4 | | | |
| Rosebrugh, D. W. | Dome | 3 | 3 | Dome | 7 | 3 |
| | 1 | 2 | 4 | 1 | 5 | 4 |
| Smith, F. W. | 3, 4 | 2 | 6 | 3, 4 | 3 | 6 |
| Wells, K. A. | 1 to 22 | 1 | 4 | .. | .. | .. |

*Member of the Black River Astronomical Society.

September 5, 1951.

# Comet Notes

By G. VAN BIESBROECK

The eight and ninth comet discoveries of the year were announced during the summer.

Comet 1951 *h* (Periodic Comas Sola) was recognized by L. E. Cunningham on several photographs taken at the Mount Wilson and Palomar Observatories early in July. This object does not come to perihelion until 1952 September 10, but backward computation from the orbit by Miss Vinter Hansen showed that it was favorably located in Cetus. The magnitude was given as 19.5 for July 9, and the position was within 15″ of the prediction. A slow rise in brightness is to be expected, magnitude 18.6 being reached by September 1.

Comet 1951 *i* (Wilson-Harrington) is the fourth new comet of the year. It was found at the Palomar Observatory in the course of the sky survey with the 40-inch Schmidt telescope, sponsored by the National Geographic Society of Washington. The first announcement came on August 7 and gave the following data:

1951 Aug. 6. 18056 U.T.
R.A. $17^h\ 35^m.7$ Decl. $-6°\ 20'$
Daily motion $-2^m\ 30^s$ $-10'$
Magnitude 10. Central condensation with tail less than 1°.

The comet was photographed here on August 9 and 10 and found to be enormously fainter than was transmitted by the discoverers, which accounts for the fact that only Mount Wilson and Yerkes positions have been published to date. I estimated the total magnitude as 15 on August 9 and an observation made here last night shows it hardly brighter. Fig. 1 is an 8 times enlargement of this 20-

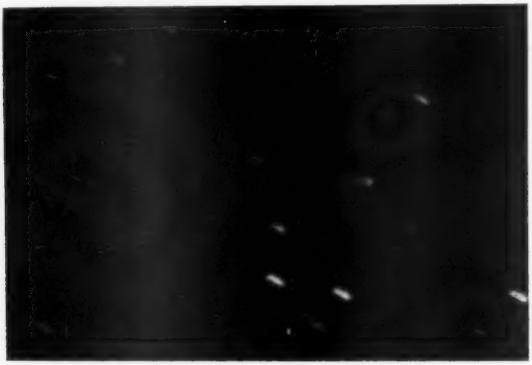

Figure 1
Comet 1951 *i*

minute exposure which was guided for the motion of the comet so that the stars appear as short trails. One can see the well-defined coma and a little tail 2′ long in the easterly direction.

From a three-day arc, the Berkeley computers Mowbray and Franklin have deduced the following preliminary orbit:

Perihelion 1952 Jan. 15.55 U.T.

| | | |
|---|---|---|
| Node to perihelion | 267°02 | 1951.0 |
| Longitude of node | 75.59 | |
| Inclination | 152.95 | |

Perihelion distance 0.78824 Astr. Units.

Fig. 2 shows the geometric relation of the comet to the earth as it passes

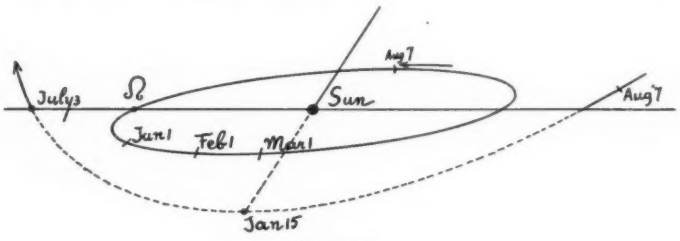


FIGURE 2
RELATIVE POSITIONS OF COMET 1951 *i* AND THE EARTH

through perihelion. The closed ellipse indicates the earth's orbit and its location at the time of discovery August 7 as well as the positions early next year. The comet describes the open curve being first above the plane of the ecliptic, passing south of it during the month of August as indicated by the dotted arc, and moving above the ecliptic again after 1952 July 3. A minimum distance of 0.40 astronomical units is reached on February 5 when a maximum brightness of 7th magnitude is foreseen. The comet is now an evening object in Ophiuchus, but before long it will be lost in the twilight. When it emerges in the morning sky around the turn of the year, it will have gained considerably in brightness, but will be best placed for southern observers. The general course is indicated by the rough ephemeris:

| | | | h m | ° ′ | m |
|---|---|---|---|---|---|
| 1951 | Dec. | 20 | 16 1 | —29 55 | 10.3 |
| 52 | Jan. | 9 | 16 5 | —39 19 | 8.9 |
| | Jan. | 29 | 18 48 | —72 54 | 7.1 |
| | Feb. | 18 | 2 50 | — 7 47 | 8.9 |
| 1952 | Mar. | 9 | 3 10 | +10 30 | 11.4 |

There are no comets visible in small telescopes at this time. COMET 1951 *f* (Periodic Tuttle, Giacobini, Kresák) was last recorded here August 4 as a small diffuse nebulosity of magnitude 17.5 which could no longer be found on plates taken August 24 showing stars down to 18.5 magnitude.

Before the end of the year, two expected periodic comets which come to perihelion in 1952 will probably be recovered: they are COMET SCHAUMASSE (1911 VII) and GRIGG-SKJELLERUP (1902 II). Also COMET 1950 *c* (Minkowski) should again become visible in the morning sky as shown by the following prediction by Bobone (H.A.C. 1128):

| | | h m | ° ′ | m |
|---|---|---|---|---|
| Oct. | 1 | 9 32.6 | —16 38 | 12.3 |
| | 21 | 29.6 | 18 50 | 12.4 |
| Nov. | 10 | 20.1 | 21 29 | 12.4 |
| | 30 | 9 02.2 | 23 41 | 12.5 |
| Dec. | 20 | 8 35.3 | —25 02 | 12.6 |

Williams Bay, Wisconsin, September 4, 1951.

# General Notes

## Ilmari Bonsdorff
## 1879-1950

Ilmari Bonsdorff, Finnish astronomer and geodesist, was educated in Finland, Russia, and Germany. When I first met him in 1913 at Poulkovo Observatory, his reputation had already gained for him an invitation to be the director of Cordoba Observatory, an invitation which he had declined.

On cloudy nights at Poulkovo, astronomers used to gather during the later hours for a cup of tea and talk on everything from astronomy to politics. Ilmari drank his tea and listened, but said little, because his Russian left much to be desired. But we all acknowledged his profound grasp of the problems of fundamental astronomy. He had made very important improvements in the technique of observing absolute declinations: thus he introduced the method of quickly reversing the vertical circle during the transit of a star to eliminate the zero point error of the circle; he discovered "room" refraction caused by the difference of the temperature inside and outside the observing pavilion; and he constructed a device for the direct measurement of the flexure of the telescope tube. Equally ingenious was his work aiming to eliminate the systematic differences between the declination systems of Poulkovo and Nicolaiev. The culmination of all this work was his outstanding *Catalogue of Declinations of 1426 Stars for 1915.0* published in 1922 in the *Annals of the Finnish Academy of Sciences.*

In 1917, Finland achieved its independence and Bonsdorff was appointed Director of the Finnish Geodetic Institute which was yet to be organized. Among his many duties in the ensuing thirty years was the fixing of the boundary line between Finland and Soviet Russia, first in 1921, again in 1940, and then after the end of World War II. He was responsible for the organization of the Baltic Geodetic Commission and served as its secretary for many years.

In 1943, Bonsdorff suggested the use of a total solar eclipse to connect the geodetic networks of the European and American continents using the moving camera technique of Banachiewicz. Ordinary triangulation is unable to bridge the Atlantic ocean, but the four contacts observed at two widely separated locations supply the missing connection. The method was successfully applied during the eclipse of May 20, 1947, when two Swedish and two Finnish expeditions were sent to South America and West Africa. Similar observations were made in 1948 in the Far East by the expeditions of the National Geographic Society.

Ilmari Bonsdorff was a man of great charm, and, although a stubborn defender of his scientific views, he never lost friends in an argument. He was a hard worker whose contributions attest the magnitude of his imagination, intellect, and character. A *festschrift* dedicated to him was published in honor of his seventieth birthday. His return to Finland in 1917 was largely motivated by his patriotism, but he remained a concerned friend of Russian astronomers to the end of his days. He is survived by his widow of Russian birth who was a computer at Poulkovo. One son and three daughters also survive.

—A. N. Vyssotsky.

Leander McCormick Observatory, University of Virginia.

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**Dr. Frederick C. Leonard** of the University of California, Los Angeles, lectured, with slides and specimens, on "The Simplified Classification of Meteorites," before the Los Angeles Astronomical Society, meeting at the Griffith Observatory and Planetarium, on August 6, 1951.

**Van de Kamp Reprints Available.** A reprint of the series of articles entitled "Long-Focus Photographic Astrometry" (POPULAR ASTRONOMY, February, March, April, May, 1951) by Peter van de Kamp will be sent to interested persons, after receipt of a written request addressed to Sproul Observatory, Swarthmore College, Swarthmore, Pennsylvania, U. S. A.

**Provisional Sunspot Numbers for July, 1951***

| | | | | | |
|---|---|---|---|---|---|
| 1 | 17 | 11 | 112 | 21 | 26 |
| 2 | 16 | 12 | 96 | 22 | 28 |
| 3 | 36 | 13 | 95 | 23 | 70 |
| 4 | 50 | 14 | 92 | 24 | 78 |
| 5 | 32 | 15 | 90 | 25 | 61 |
| 6 | 56 | 16 | 40 | 26 | 52 |
| 7 | 69 | 17 | 45 | 27 | 60 |
| 8 | 86 | 18 | 48 | 28 | 79 |
| 9 | 105 | 19 | 40 | 29 | 61 |
| 10 | 109 | 20 | 33 | 30 | 66 |
| | | | | 31 | 58 |

Mean Value for July
R = 61.5

**Provisional Sunspot Numbers for August, 1951***

| | | | | | |
|---|---|---|---|---|---|
| 1 | 64 | 11 | 121 | 21 | 54 |
| 2 | 71 | 12 | 112 | 22 | 62 |
| 3 | 55 | 13 | 82 | 23 | 38 |
| 4 | 57 | 14 | 66 | 24 | 42 |
| 5 | 73 | 15 | 62 | 25 | 24 |
| 6 | 74 | 16 | 58 | 26 | 8 |
| 7 | 83 | 17 | 54 | 27 | 6 |
| 8 | 102 | 18 | 49 | 28 | 8 |
| 9 | 121 | 19 | 66 | 29 | 24 |
| 10 | 132 | 20 | 67 | 30 | 15 |
| | | | | 31 | 40 |

Mean Value for August
R = 61.0

*From the Zürich Observatory, furnished by Mr. Neal J. Heines.

**The Leuschner Observatory.** By action of the Board of Regents of the University of California and in conformance with a recommendation of the Astronomy Department in Berkeley, The Students' Observatory on the Berkeley campus has been renamed The Leuschner Observatory in recognition of Professor A. O. Leuschner's services to astronomy and the University.

**The Second International Congress on Astronautics.** The Second International Congress on Astronautics which was organised by the British Interplanetary Society was held in London from September 3-8. It was attended by nearly 50 delegates from the Argentine, United States, Spain, France, Great Britain, Germany, Austria, Italy, Sweden, and Switzerland, representing a total of about 4,500 members. During the first two days of the proceedings an International Astronautical Federation was formed with its headquarters in Switzerland. Its first President is Dr. Eugen Sänger, internationally renowned rocket and ram-jet engineer and leading authority on high-altitude high-speed flight. He was in charge of a research establishment at Trauen, Germany, during World War II where, together with Dr. Irene Bredt who also attended the Congress, he worked on a rocket-propelled round-the-world bomber. This was to have weighed 100 tons and would have circled the earth in a few hours. The vice-presidents

are Dr. G. Loeser of the Gesellschaft für Weltraumforschung, Germany, and Mr. Andrew G. Haley of the American Rocket Society.

During the latter half of the Congress a series of 17 papers were read dealing with various aspects of orbital vehicles, or artificial satellites as they are sometimes known. Some of the topics dealt with were the minimum requirements for an instrument-carrying close-orbit vehicle, the danger to space-stations from meteors, the optimum orbit for radar tracking and descent from satellite orbits by gliding. The next Congress will be held in Germany in September, 1952.

J. HUMPHRIES.

The British Interplanetary Society, London, England, September 9, 1951.

**International Astronomical Union General Assembly.** The Executive Committee of the I.A.U. met in Paris during the second week of September and decided to hold the next General Assembly in Rome sometime in September, 1952. From our brief communication it appears that this plan is satisfactory to all concerned. Full details will be sent to all the members of the I.A.U. as soon as they become available.

J. J. NASSAU, *Chairman*,
U. S. National Committee, I.A.U.

## Book Reviews

**Johannes Kepler, Life and Letters,** by Carola Baumgardt. (The Philosophical Library, Inc., 15 E. 40th St., New York City. 209 pp. $3.75.)

In the introduction of this book, Albert Einstein says about the letters: "There we meet a finely sensitive person, passionately dedicated to the search for a deeper insight into the essence of natural events, who, despite internal and external difficulties, reaches his loftily placed goal."

In his scientific thinking one remarks the strange mixture of modern astronomy and astrology of the Middle Ages. In his religion he was a Protestant with liberal thoughts, who was driven out of the Catholic town of Graz in Austria, but had also his difficulties with the Lutheran church in Linz. The trial of his mother as a witch, his poor health, the financial troubles caused by unpaid salary, the Thirty Years' War are the additional difficulties under which Kepler had to work. By reading his letters, one realizes better the genius of this great astronomer.

The translation in English is sometimes insufficient in this book. Inaccurate astronomical terms as "knots" for nodes, "astrogist" for astrologer, "periodic times" for sidereal periods are unnecessary. On pages 26 and 27, one has to read 1595 instead of 1495. On some pages, one would like to have more footnotes. For example, no explanation is given of what is meant by "the wavelengths of certain planets" on page 124.

L. BINNENDIJK.

Goodsell Observatory, Carleton College.

**The Planet Mars,** by Gérard de Vaucouleurs, translated by Patrick A. Moore. (The Macmillan Co., 60 Fifth Ave., New York City. 87 pp. $2.00.)

In this interesting little book, a summary is given of the main scientific data we have about the planet Mars today. The book is divided into the following chapters: generalities, the polar caps, the bright regions of Mars, the atmosphere, climates, the dark regions of Mars, the canals, life on Mars. The writer clearly shows which data are accurate and which are at the limit of our ability to see or to measure, and draws the obvious conclusions. Some of the author's own observations are included. More extensive data can be found in the original French edition: *Physique de la planète Mars.* (Editions Albin Michel, Paris. 420 pp.)

Goodsell Observatory, Carleton College. L. BINNENDIJK.